DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-30

AQUATIC DISPOSAL FIELD INVESTIGATIONS COLUMBIA RIVER DISPOSAL SITE, OREGON

EVALUATIVE SUMMARY

by

Charles G. Boone, Mitchell A. Granat, Michael P. Farrell

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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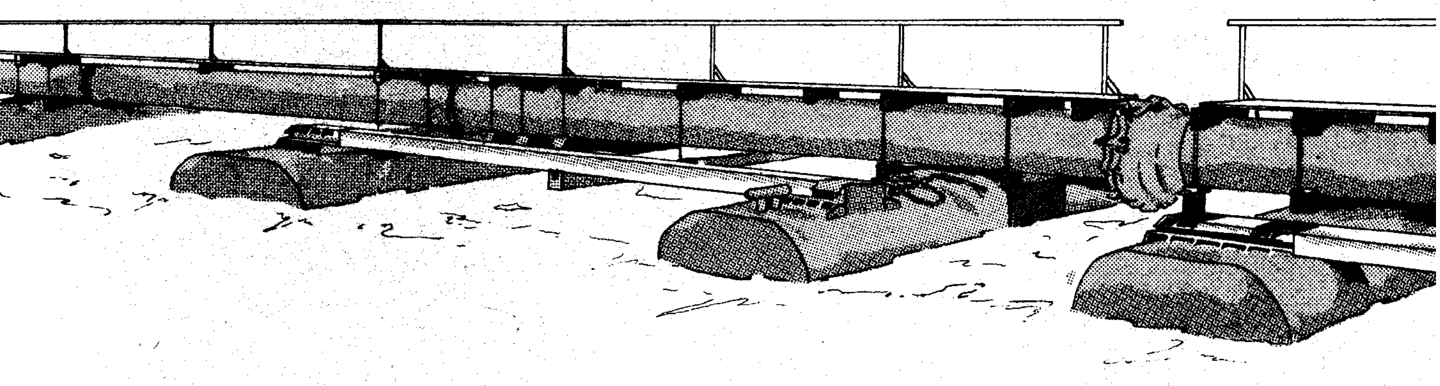

Prepared for Office, Chief of Engineers, U. S. Army
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Under DMRP Work Unit No. 1A07

AQUATIC DISPOSAL FIELD INVESTIGATIONS
COLUMBIA RIVER DISPOSAL SITE, OREGON

APPENDIX A: Investigation of the Hydraulic Regime and Physical Nature of Bottom Sedimentation

APPENDIX B: Water Column, Primary Productivity, and Sediment Studies

APPENDIX C: The Effects of Dredged Material Disposal on Benthic Assemblages

APPENDIX D: Zooplankton and Ichthyoplankton Studies

APPENDIX E: Demersal Fish and Decapod Shellfish Studies

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESYV

30 June 1978

SUBJECT: Transmittal of Technical Report D-77-30

TO: All Report Recipients

1. The technical report transmitted herewith contains a summary of the results of several research efforts (Work Units) undertaken as part of Task 1A, Aquatic Disposal Field Investigations, of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 1A was part of the Environmental Impacts and Criteria Development Project, which had as a general objective evaluation of the effects of open-water disposal on biota and water quality at disposal areas. This report is a summary of the physical, chemical, and biological studies that were conducted at the Mouth of the Columbia River Disposal Site in Oregon. This research site was one of five studied under the DMRP in various geographical regions of the United States.

2. This report, Aquatic Disposal Field Investigations, Columbia River Disposal Site, Oregon; Evaluative Summary, presents an overview of five research efforts conducted at the Columbia River Disposal Site. Appendices A-E to this report, the titles of which are listed on the inside front cover of this report, describe these research efforts. The evaluative summary provides additional results, interpretations, qualifications, and conclusions not found in the appendices and, in addition, provides a comprehensive summary and synthesis of the entire study.

3. The purpose of the Columbia River study was to determine the physical, chemical, and biological effects of open-water disposal of dredged material in the nearshore Pacific Ocean adjacent to the mouth of the Columbia River. In addition, this study involved the monitoring of dredged material disposal at a designated disposal site and an estimation of the short-term impacts of the disposal operation and the subsequent recolonization of the area.

4. Physical data indicate that the dredged material removed from the Columbia River entrance channel was sedimentologically and mineralogically different than ambient shelf sediments and that the dredged material

deposit was relatively stable, but was gradually migrating towards the north. Chemical studies suggest that the study area rapidly responded primarily to tidal and river discharge effects. Dredged material disposal at the study site had no measurable short-term chemical effects on water or sediment quality. Biological data indicate that disposal had a measurable physical impact both on benthic macroinvertebrates and demersal fin-fish. Benthic macroinvertebrate densities were significantly lower following disposal while benthic diversity and evenness values were significantly higher following disposal. Demersal fish studies indicate that species diversity and richness measures were depressed immediately after disposal; however, these indices were similar to those of unimpacted sites 5 months after disposal.

5. Conclusions of this report, based on the data presented, indicate that the disposal effects were primarily physical and biological in nature. Dredged material deposited at the disposal area slightly altered the textural composition of the bottom sediments and also buried less motile benthic macroinvertebtates such as tube-dwelling polychaetes and amphipods. Recolonization of the disposal area was seen to occur shortly after disposal and apparently was accomplished by benthos burrowing up through the dredged material, by migration into the area, and by reproduction and/or recruitment of benthos from outside the affected area.

6. Results of the Columbia River research will be useful in a regional sense for evaluating the possible environmental impacts of open-water disposal in the nearshore Pacific. These studies will be helpful in planning future dredging and disposal projects involving open-water disposal in order to minimize adverse environmental effects.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aquatic environment	Dredged material disposal
Bottom sediment	Field investigations
Columbia River	Sedimentation
Dredged material	Waste disposal sites

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A multidisciplinary study was conducted offshore of the mouth of the Columbia River to characterize the baseline physical, chemical, and biological aspects of the nearshore zone and to investigate the effects of open-water disposal on the study area. The results of this study are summarized in this report. Detailed results of the various research efforts are contained in Appendices A-E.

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20. ABSTRACT (Continued).

Physical data analyzed during the study indicate that dredged material deposited in the nearshore zone off the mouth of the Columbia River maintains its identity relative to surrounding sediments for periods of years and that such material migrates towards the north at a rate of approximately 0.6 kilometre per year.

Chemical data suggest that the release of dredged material at the experimental disposal area has no measurable effect on either ambient water quality or quality of the sediments. Dredged material removed from the Columbia River entrance channel can be characterized as fine to medium sand with insignificant levels of pollutants. Bottom sediments examined from the tidal delta in the region of disposal site B consistently showed higher levels of nutrients and metals than sediments from adjacent sampling sites.

Biological studies indicate that the disposal of dredged material had a measurable effect on both the benthic macroinvertebrates and the demersal finfish at the experimental disposal area. Benthic macroinvertebrate stations exposed to direct burial by dredged material had significantly higher diversity values and lower density values than unaffected stations. These differences persisted for 8 to 10 months following disposal. Immediately after disposal, there was a significant reduction in the densities of 15 of the 31 dominant species in the study area. Demersal fish studies indicate that species diversity, species richness, and catch per unit effort indices were depressed following disposal. This condition persisted for several months following disposal. Significant spatial or site differences were found in 10 of the 11 numerically dominant finfish species, and significant temporal differences were found in the catch data for 9 of the 11 dominant species.

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PREFACE

This report presents a summary of the results of a comprehensive investigation of open-water disposal of dredged material in the nearshore Pacific Ocean off the mouth of the Columbia River. This multidisciplinary investigation was conducted between August 1974 and June 1976 as part of the Dredged Material Research Program (DMRP), under Work Unit No. 1A07. The DMRP was sponsored by the Office, Chief of Engineers, U. S. Army, and was managed by the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

This report was prepared by Charles G. Boone, Mitchell A. Granat, and Michael P. Farrell under the general supervision of Dr. John Harrison, Chief of EL, and Dr. Roger T. Saucier, Special Assistant for Dredged Material Research. Dr. Robert M. Engler was Project Manager.

Directors of WES during the period of this investigation were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

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AQUATIC DISPOSAL FIELD INVESTIGATIONS
COLUMBIA RIVER DISPOSAL SITE, OREGON

EVALUATIVE SUMMARY

PART I: INTRODUCTION

Background

1. The Corps of Engineers was authorized by Congress in the 1970 River and Harbor Act to initiate a comprehensive nationwide study to provide more definitive information on the environmental impact of dredging and dredged material disposal operations and to develop new or improved dredged material disposal practices. The study was divided into four phases:

- a. Problem identification and assessment.
- b. Development of a research program.
- c. Accomplishment of needed research.
- d. Field evaluation of new or improved disposal practices.

The U. S. Army Engineer Waterways Experiment Station (WES) was assigned responsibility for the research accomplishment which was designated the Dredged Material Research Program (DMRP).

2. The DMRP was a comprehensive program of research and experimentation, the planning and implementation of which were accomplished by an interdisciplinary team established at WES as part of the Environmental Laboratory. The program was divided into four major research projects:

- a. Environmental Impacts and Criteria Development Project.
- b. Habitat Development Project.
- c. Disposal Operations Project.
- d. Productive Uses Project.

3. Each project was further subdivided into several research task areas. Within the first project area, there were six research tasks:

- a. Task 1A. Aquatic Disposal Field Investigations.

b. Task 1B. Movements of Dredged Material.

c. Task 1C. Effects of Dredging and Disposal on Water Quality.

d. Task 1D. Effects of Dredging and Disposal on Aquatic Organisms.

e. Task 1E. Pollution Status of Dredged Material.

f. Task 1F. Confined Disposal Area Effluent and Leachate Control.

4. The investigation described in this report was conducted under Task 1A. The mouth of the Columbia River was one of five regional aquatic disposal field investigation study areas selected. Other study areas were located at Eatons Neck in Long Island Sound; offshore of Galveston, Tex.; at Ashtabula, Ohio; and in Puget Sound, Wash., near the entrance to the Duwamish Waterway. Each of these areas was selected after a comprehensive review of potential open-water disposal study sites.

Site Selection

5. For the purpose of evaluating potential open-water disposal sites for detailed investigation, the waters adjacent to six major shoreline reaches of the continental U. S. were selected. These were the:

a. North Atlantic, from Cape Hatteras north.

b. South Atlantic, from Cape Hatteras south.

c. Gulf of Mexico.

d. South Pacific, from Cape Mendocino south.

e. North Pacific, from Cape Mendocino north.

f. Great Lakes.

6. In all, some 119 coastal open-water disposal sites in these waters were evaluated. The results of this site selection exercise are reported in Mathis et al.[1] Along the North Pacific coast, 32 open-water disposal sites were considered. Of these, only 6 passed the preliminary evaluation criteria, which included such factors as regulatory approval for open-water disposal, disposal in at least 10 m of water, annual

disposal capability, availability of expertise to conduct research, and regional representation. The 6 North Pacific sites which offered the greatest potential for detailed research were:

a. Columbia River mouth, Oreg.

b. Yaquina Bay and Harbor, Oreg.

c. Siuslaw River, Oreg.

d. Coos Bay, Oreg.

e. Rogue River Harbor, Oreg.

f. Humboldt Bay, Calif.

Locations of these sites are shown in Figure 1.

7. The Columbia River site was ultimately selected for study purposes because it was accessible for monitoring, was considered to be a top-priority ongoing dredging project with sufficient quantities of available material, and had major research facilities nearby.

Dredging/Disposal History and Requirements

8. The present Columbia River entrance channel (Figure 2) is 14.63 m deep, 0.8 km wide, and approximately 3.2 km long and is protected by two converging rubble-mound jetties. The north jetty is about 4.0 km long, and the south jetty is about 10.6 km long. Within the lower river, the authorized entrance channel proceeds approximately 4.8 km farther upstream to the vicinity of Sand Island. In order to provide a stabilized entrance channel across the ocean bar, about 1.5 million m^3 of bottom sediment is dredged from the channel each year. The normal dredging season for this project is between April and August. During the remaining 7 months, weather and sea conditions are generally adverse and result in excessive amounts of downtime.

9. Annual maintenance dredging of the entrance channel is normally accomplished by the hopper dredges BIDDLE and HARDING. These dredges have hopper capacities of 2,340 and 2,050 m^3, respectively, and are capable of dredging 574,773 and 407,135 m^3 per month (5-year means). Other information on the disposal process (based on operations of disposal areas B, D, E, and F) is given in the following tabulation:

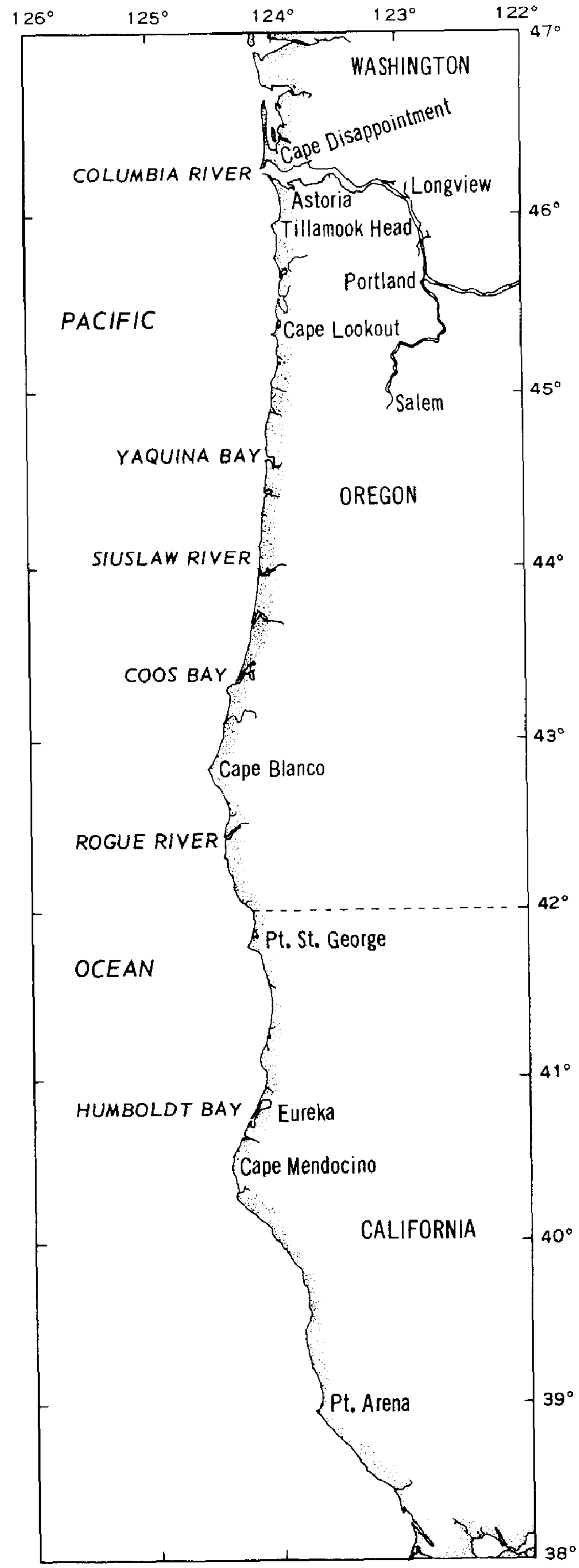

Figure 1. Locations of open-water disposal sites considered for study along North Pacific coast

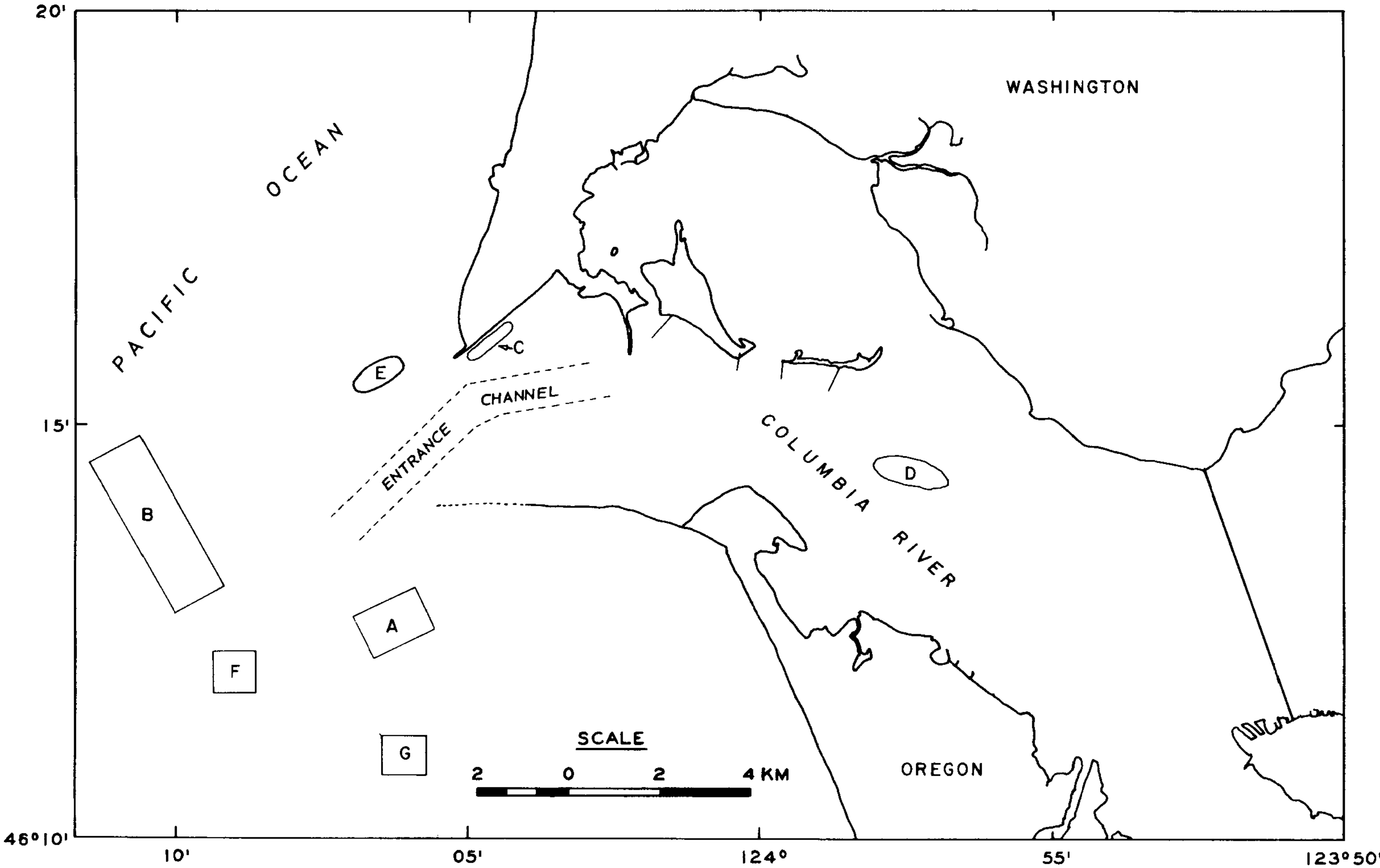

Figure 2. Columbia River entrance channel and disposal areas

Average Volume of Material in Each Dump m^3	Average Time Required for Each Dump min	Number of Dumps per Month	Total Number of Dumps per Year at Disposal Areas B, D, E, and F
2219	10.22	36 to 161 (Highly variable, depending on weather and distance from dredging site)	2111

10. Of the 1.5 million m^3 of dredged material removed annually from the entrance channel, most has been disposed of at disposal areas B and E. Table 1 lists the disposal history at the mouth of the river since 1957. The locations of the various disposal areas are shown in Figure 2. The sizes of disposal areas B, D, E, and F are given in the following tabulation:

	Disposal Area			
	B	D	E	F
Depth, m below mllw*	22 to 43	11 to 18	9 to 18	37 to 41
Approximate dimensions, m	3810 by 1280	1829 (elliptical)	Not known (elliptical)	997 by 954

* Mean lower low water.

11. Disposal area E has been used primarily during ebb and slack tides to prevent material from returning to the channel. Area B is used at other times. Area D, in the estuary adjacent to Desdemona Sands channel, has been used when dredging upriver shoals or when weather and sea conditions offshore have been adverse. Use of disposal areas A and F was shown by hydraulic model tests to have an adverse effect on shoaling in the entrance channel and has generally been discontinued. The use of area D probably has little effect on shoaling in the entrance channel; however, it is located in an area where flood flows predominate and, on a long-term basis, may result in increased levels of suspended matter in the estuary. Disposal area C, located just inside the north jetty, received moderate amounts of material until 1971, after which its

Table 1

Disposal of Dredged Material at the Mouth of the Columbia River (1957-1976)

Year	Cubic Metres of Dredged Material Deposited at Cited Disposal Area							Total
	A	B	C	D	E	F	G	m^3
1957	1,227,650	933,792	322,709	641,049				3,125,200
1958	4,691	1,739,203		249,830				1,993,724
1959		1,464,152		505,406				1,969,558
1960		1,473,513		468,412				1,941,925
1961		1,405,214		227,132				1,632,346
1962		1,775,561	2,170	483,690				2,261,421
1963		1,319,559	554,041	179,475				2,053,075
1964		393,685	1,115,671	522,327				2,031,683
1965		516,799	921,393	1,228,436				2,666,628
1966		1,537,329	22,854	1,863,637		164,387		3,588,207
1967		1,117,487	816	271,198		322,705		1,712,206
1968		1,467,390		83,792				1,551,182
1969		1,545,655		68,080				1,613,735
1970		1,139,074		2,340				1,141,414
1971	39,030	1,100,269	10,565	184,792				1,334,656
1972	9,936	1,972,389		219,930		1,442		2,203,697
1973		2,333,253		313,204	222,830	2,340		2,871,627
1974		760,042		387,423	1,658,034	22,267		2,827,766
1975		254,950		1,379,211	3,736,221	21,056		5,391,438
1976		362,310		801,714	1,510,759	5,991	460,964	3,141,738
Total	1,281,307	24,611,626	2,950,219	10,081,078	7,127,844	540,188	460,964	47,053,226

Note: Data prior to 1966 are for calendar years.

use was discontinued. Use of this area was primarily restricted to times when weather conditions prevented use of offshore areas.

12. An experimental disposal area, area G, was selected for investigation in June 1975. It was located south of area A in approximately 26 m of water and was marked with a special purpose buoy. This area had not been used for disposal in the past and hence provided an opportunity to study disposal effects in an open-water environment. During the period 9 July 1975 to 26 August 1975, 458,632 m^3 of dredged material removed from the entrance channel was disposed of at area G.

Purpose and Scope

13. The investigation was begun in August 1974 as an effort to identify and evaluate the effects of open-water disposal on the flora and fauna at the disposal site, as well as to measure rates and patterns of dispersion of dredged material following disposal. It was also designed to provide more definitive information on the environmental impacts of open-water dredged material disposal. Specifically, the investigation was designed to identify how physical, chemical, and biological factors associated with disposal affect the benthic community structure at the disposal site and how the benthos recover or recolonized after disposal operations are terminated. Due to the lack of information concerning present coastal disposal operations, this research included evaluations of both short- and long-term effects of such operations. The research plan used to design the investigation is described in Becker et al.[2]

14. Field research was separated into physical, chemical, benthic, plankton, and fishery studies. All studies were performed for WES under contract. A chronology of the field program is given in Table 2.

15. Physical studies at the site were conducted by the Oceanography Department, University of Washington, with Drs. Joe S. Creager and Richard W. Sternberg as principal investigators. These studies included an evaluation of the nearshore hydraulics and sediment transport, geological sediment sampling, minerologic analyses, and bathymetric and geophysical surveying. On a seasonal basis, bottom boundary layer

Table 2

Chronology of Field Research Program (August 1974-June 1976)

Study Description	Baseline Surveys										Disposal and Monitoring			Postdisposal Surveys									
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
A. Physical studies																							
(1) Geological surveys	✓	✓	✓	✓	✓				✓		✓		✓	✓	✓	✓	✓						
(2) Bathymetry/geophysical surveys	✓											✓		✓		✓		✓		✓			
(3) Pressure transducer measurements						|—	—	—	—	—	—	—	Not recovered	—	—	—	—	—	—	—	—	—|	
(4) Boundary layer determinations									2*		1		2				2						
B. Chemical studies																							
(1) Water column nutrients		✓				✓					✓	✓	✓		✓								
(2) Water column metals											✓	✓	✓		✓								
(3) Sediments		✓				✓					✓		✓		✓								
C. Benthic studies																							
(1) Macrobenthos			✓		✓	✓			✓		✓		✓	✓				✓			✓		✓
(2) Beam trawl					✓				✓		✓		✓	✓									
D. Plankton studies																							
(1) Phytoplankton		✓																					
(2) Zooplankton		✓				✓		✓			✓	✓	✓		✓								
(3) Ichthyoplankton		✓				✓		✓			✓	✓	✓		✓								
E. Fisheries studies																							
(1) Demersal finfish			✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		
(2) Decapod shellfish			✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		

* Indicates number of instruments deployed.

measurements were made using self-contained instrumented tripods. The detailed results of these studies are contained in Appendix A to this report.

16. Water quality and sediment chemistry studies at the site were conducted by Drs. Robert L. Holton, Norman H. Cutshall, Louis I. Gordon, and Lawrence F. Small of the School of Oceanography, Oregon State University. Various chemical properties were studied on a regular basis in the water column and sediments from both the experimental disposal area (G) and adjacent reference areas. Detailed results of these studies are contained in Appendix B to this report.

17. Drs. Andrew G. Carey and Michael D. Richardson of the School of Oceanography, Oregon State University, conducted the benthic studies at the site. During this portion of the investigation, a temporal series of benthic samples was taken to determine the chronic effects of disposal on benthic communities and their ability to recolonize the site after disposal. These results have been analyzed and are contained in more detail in Appendix C to this report.

18. Plankton studies were conducted by Drs. Robert L. Holton and Lawrence F. Small of the School of Oceanography, Oregon State University. During this aspect of the investigation, seasonal plankton samples were taken to evaluate primary production and species composition, distribution, and abundance with particular emphasis on zooplankton and ichthyoplankton groups. The results of these studies are discussed in more detail in Appendix D to this report which has been microfiched.

19. Demersal fish and decapod shellfish studies were conducted by the National Marine Fisheries Service Biological Field Station, Hammond, Oreg. Principal investigators were Mr. Joseph T. Durkin and Ms. Sandy J. Lipovsky. The objectives of these studies were to describe the composition and spatial and temporal distribution of demersal fish assemblages in the nearshore area and to define the food chain relationships and species-habitat associations within the study area and to describe how these are affected by dredged material disposal. The results of the fisheries studies are discussed in more detail in Appendix E.

PART II: SITE-SPECIFIC LITERATURE

20. While numerous studies have been conducted on the physical, chemical, and biological aspects of the nearshore zone in the Northeast Pacific, very few are specific to the Columbia River mouth, an area known for its strong surface currents, summer upwelling, and hazardous wave conditions. The greatest single source of biological, chemical, and physical information on the study area has been compiled by Pruter and Alverson in The Columbia River Estuary and Adjacent Ocean Waters, Bioenvironmental Studies,[3] which contains some 30 chapters on the subject. Particular emphasis, however, has been placed on the occurrence and distribution of radionuclides in the river and nearshore ocean system. Renfro et al.[4] have written a two-volume publication, Oceanography of the Nearshore Coastal Waters of the Pacific Northwest Relating to Possible Pollution, which includes 21 chapters, 8 appendices, and a bibliography of more than 3100 entires. Both of the above-mentioned references provide very useful background information over a large geographical scale; however, detailed studies are not included for the vicinity of the mouth of the Columbia River.

21. In a short-term study conducted by the National Marine Fisheries Service, Durkin[5] suggested that a numerical reduction of fish at the ocean disposal areas followed dredged material disposal. The results of this study, however, could not be quantified due to the short-term nature of the sampling program and the lack of available background information on the natural spatial and temporal distributions of the observed fish species.

22. Other pertinent site-specific literature is discussed in greater detail in each of the respective Appendices.

PART III: DESCRIPTION OF STUDY AREA

Hydrology

23. The Columbia River, the largest river on the Pacific coast of North America, drains an area of about 670,810 km^2 during its 1947-km course from British Columbia to the Pacific. The Columbia forms the boundary between Oregon and Washington from just below Pasco, Wash., to the coast. From the former point, it flows westward through the Cascade Range, north and westerly through the Coast Range, and into the Pacific Ocean about 16 km below Astoria, Oreg.[6] Principal tributaries that enter the Columbia in Washington are the Spokane, Okanogan, Wenatchee, Yakima, Snake, Lewis, and Cowlitz Rivers. In Oregon, the main tributaries are the Umatilla, John Day, Deschutes, and Willamette Rivers.[6]

24. The Columbia River mean annual discharge is about 7,300 m^3/sec, the range being between about 3,000 and 20,000 m^3/sec.[7] Peak discharges occur during May and June as a result of snowmelt. Minor peaks also occur during the winter, resulting from rainfall west of the Cascades. Lower flows occur from August to October.

25. The Columbia River forms the navigable approach to the Portland-Vancouver Area for deep-draft shipping. There are 11 ports between the Pacific Ocean and Portland which have been developed to support rail, highway, air freight, and barge services. The river and its tributaries are used to ship paper and related products within the region and for shipping food, lumber, paper, and chemicals in the Pacific Northwest. Virtually all foreign shipping is by water with primary exports being wood and wood products.

Geography

26. The mouth of the Columbia River is 1000 km north of San Francisco Bay and 480 km south of Seattle. Astoria, Oreg., is approximately 16 km upstream from the mouth of the river and 138 km downstream from Portland. At the mouth of the river, the mean tidal range is 1.98 m.

Tides at the mouth are the mixed semidiurnal type which are characteristic of the Northeastern Pacific. The primary dredged material disposal area, area B, is located about 4.6 km west of the tip of the south jetty or about 8.3 km offshore. Water depths in the study area on the nearshore continental shelf range from 23 to 38 m below mllw.

Climate

27. The climate of the region is best characterized as a marine, Pacific Northwest type having wet winters and dry summers. Principal climatic controls are topography, proximity to the Pacific Ocean, and prevailing direction of mid-latitude winds. Local weather is primarily dominated by the general circulation pattern of the atmosphere over the Northeast Pacific. A seasonal cyclonic precipitation pattern is established by the general eastward flow of low-pressure centers. During 1975, the annual precipitation recorded at Astoria by the National Weather Service was 205.18 cm (80.78 in.). Since the area is largely dominated by maritime air, the climate is temperate, and both annual and diurnal temperature ranges are relatively small. Average maximum temperature is about 8°C. The temperature and general climatic patterns described above change drastically east of the river mouth as the Coast and Cascade Ranges begin to influence the weather patterns.

28. The strongest winds experienced along the Oregon coast are generally from the south or southwest. During the fall and winter months, these winds are associated with large low-pressure systems which move coastward off the Pacific Ocean. Gale-force winds are not uncommon along the coast during these months. Intense low-pressure systems have been known to strike the coast in rapid succession (2 to 3 days of each other) during winter months. Winds associated with these systems occasionally reach 97 to 113 km/hour. During the spring and summer months (May-September), winds moderate and become more northerly.

Geology

29. The Columbia River gorge east of Portland divides the Cascade

Range. The Cascades are composed primarily of volcanic flows and pyroclastics of Tertiary and Quaternary origin admixed with some intrusive igneous and sedimentary deposits. Volcanic rocks, however, form the most predominant bedrock in the Lower Columbia River drainage area. As the river continues toward the Pacific, it passes through the Coast Range which is generally no more than 610 m above sea level. Rock formations in the Coast Range are of Tertiary origin and consist predominantly of basaltic and andesitic flows. West of the Coast Range, the river flows through a narrow coastal plain before emptying into the Pacific.

30. Sediments on the nearshore continental shelf within the study area are primarily either nearshore beach sands or Columbia River bedload material. These two sediment types are mineralogically and texturally dissimilar. Sediments deposited along the Oregon Coast regime by rivers draining the Coast Range contain a high percentage of opaque, magnetic material which has been transported northward along the beach zone by littoral processes. Sediments in the study area south of the river entrance are primarily fine to very fine sand with only minor amounts of silt and clay. Predominant sediment sizes range from 2.75 ϕ (0.15 mm) to 3.25 ϕ (0.105 mm) in this area. North of the river mouth, the sediments are best characterized as very fine sands with moderate amounts of course silt and clay, which are derived primarily from the Columbia River. These particles have sizes ranging from 3.25 ϕ (0.105 mm) to 12 ϕ (0.24 μ).

31. On the other hand, sediments in the nearshore zone near the mouth of the river are composed primarily of fresh plagioclase and potassium feldspar. The general distribution of shelf sediments in the study area can be explained in terms of shoreline recession during Pleistocene sea level rise. South of the Columbia River, as mentioned above, sediments contain a high proportion of opaque heavy minerals which are transported northward along the beach zone by littoral processes. Since these minerals have a high density and relatively course grain size, they tend to remain in the surf zone. As shoreline recession proceeds, the heavy minerals form a basal layer on which midshelf and outershelf sediments are deposited. The midshelf and outershelf

sediments are characterized by high proportions of altered lithic fragments and lesser amounts of magnetic materials. These altered lithic fragments tend to become deposited in the midshelf and outershelf environments due to their lower density and fine grain size. Approximately the same distribution pattern is recognized north and west of the Columbia River tidal delta. Within the delta, the sediment distribution pattern is complicated by the transport of river sediment to the northwest from the mouth of the river. In general, the Columbia deposits its bed load and some of its suspended load on the tidal delta as a result of changes in the velocity field as its waters reach the sea. Once deposited, tidal and wave-generated currents initiate a net northwesterly transport of the sediment. This sediment transport process apparently results in a mass sorting of the material which leaves the heavy, magnetite-rich sediment near the northern half of the river mouth and transports the plagioclase-rich sediment to the northwest.

Physical Characteristics

32. The study area, as shown in Figure 3, is located adjacent to the mouth of the Columbia River on the Oregon-Washington continental shelf, where water depths range between 10 and 90 m. The Columbia River plume influences an area from latitude 40° to 49°N to as far as 600 km offshore.[8] Reductions in salinity near the river mouth are generally restricted to the upper 14 m of the water column. Salinity below 14 m varies little from 34 °/oo.[9]

33. Surface water currents along the Oregon continental shelf from September through October reportedly flow in a northerly direction, averaging 16 cm/sec.[10] Stevenson and Pattullo[11] measured southerly littoral surface currents in the coastal area during summer with speeds of 5 to 10 cm/sec.

34. Gross et al.[12] found that the predominant movement of bottom drifters is toward the river mouth with average speeds of 1.4 km/day. In this study, several drifters moved upriver about 4 km. Bottom flows north of the river mouth trend either to the north or northwest.

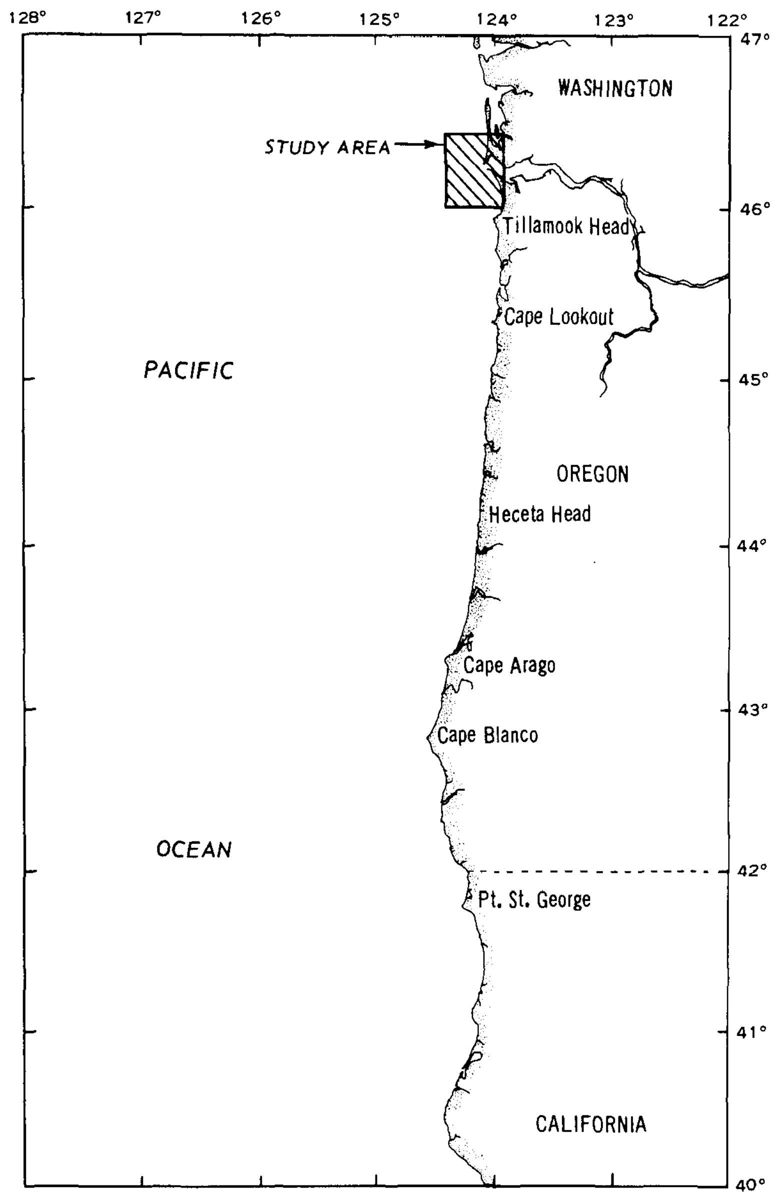

Figure 3. Location of study area

Measurements made south of the river mouth also exhibit a net north-northwest bottom flow; however, velocities are generally much lower (usually less than 20 cm/sec) than those measured to the north.

35. Waves in the study area are affected by local wind conditions as well as offshore atmospheric disturbances. During the summer, the predominant wave direction is northerly; during the winter, the reverse is true. Winter sea and swell conditions tend to be most severe, which explains the net northward movement of nearshore water over the entire year. The presence of the jetty system and the shallow ocean bar tends to cause waves and breakers which at times are precipitous. Consequently, the Columbia River entrance is one of the most dangerous and respected on the entire Pacific coast.

Water Column Chemistry

36. Water chemistry in the study area changes rapidly both in time and in space because of the dynamic environment. Changes are induced by seasonal variations in river discharge, tidal currents, wave mixing, and upwelling. The upper 15 m of the water column responds most rapidly to these mixing processes. During certain periods, the water column is stratified, while during others it is homogeneous. As a result, the distribution of a particular chemical species must be time-averaged (over tidal cycles) if it is to be considered characteristic of a specific location and time.

37. Surface water temperature in the study area varies from 5°C in the winter to about 20°C in the summer. Surface salinity near the river mouth varies considerably as it is dominated by tides and river discharge. During periods of high river discharge, surface salinity may be depressed to near 10 °/oo, while at other times it may range from 25 to 30 °/oo. Surface salinity is generally higher during the summer months, especially during periods of upwelling. Winter rains and high runoff act to depress surface salinity in the Lower Columbia River. While tidal reversals have been observed 85 km upstream and tidal fluctuations as far as 225 km upstream, the maximum intrusion of seawater

is generally less than 37 km upstream.[6]

38. Water column nutrients also undergo drastic seasonal fluctuations. In general, the highest and lowest oxygen and nutrient surface values are observed during summer, probably due to the opposing influences of photosynthetic production and upwelling. Surface oxygen levels, unless affected by strong upwelling, are about 6.3 to 7.0 mg/ℓ. Typical phosphate, nitrate, and silicate values, in the nearshore zone exclusive of upwelling, are 22, 70, and 280 μg/ℓ, respectively.[4] Changes in the concentrations of these properties in the surface water near the river mouth occur very rapidly and tend to increase as river discharge increases.

39. Very little information is available in the literature concerning trace metal concentrations in the nearshore zone. Natural inputs are through surface advection, upwelling, and runoff. Removal of trace metals from the water column may be caused by such processes as advection, biological activity, sorption, flocculation, ion exchange, precipitation, and coprecipitation.[4] Concentrations of trace metals in the water column generally are very low or below detection limits.*

Biology

40. The lower Columbia River Estuary and adjacent ocean waters support a very diverse assemblage of plants and animals. The distribution of benthic assemblages in the study area is controlled by sediment type and distance from shore. Polychaetes, crustaceans, and mollusks dominate. Several macrobenthic assemblages have been observed in the study area.

41. The distribution of planktonic communities in the area is also highly variable, for primarily the same reasons as mentioned above. Larval and juvenile fish in the area are dominated by smelt, anchovy, righteye flounder, and codfish. Abundances of larval and juvenile fish

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* Typical ranges are: cadmium 0.06 to 0.18 μg/ℓ, copper 0.6 to 30 μg/ℓ, lead 0.05 to 1.5 μg/ℓ, and mercury 0.08 to 0.36 μg/ℓ.[4]

are generally higher in the winter and spring months. The remaining zooplankton are dominated by calanoid copepods, gammarid amphipods, cumaceans, and mysids. Mysid and cumacean distributions reflect nocturnal activity patterns since they are primarily benthic animals. Haertel and Osterberg[13] have listed and described the zooplankton of the Columbia River Estuary. Marine phytoplankton communities in the vicinity of the Columbia River have often been overlooked as emphasis has been placed on larger, economically important species. The standing stock of marine diatoms and microflagellates in the Columbia River plume has been found to be greater than that in adjacent waters.[14] Inshore communities during winter months are dominated by *Asterionella formosa*, *Melosira islandica*, and *Thalassionema nitzschioides*. During the spring months, abundant diatoms include *Asterionella japonica*, *Chaetoceros compressus*, *C. radicans*, *Rhizosolenia alata*, *R. alata gracillima*, *R. delicatula*, and *R. fragilissima*.[15]

42. Numerous anadromous and marine fishes use the lower Columbia River during some stage of their life history. Dominant demersal fish include anchovy, smelt, sole, poacher, snailfish, tomcod, and sanddab, while decapod shellfish are dominated by four species of crangonid shrimp and the dungeness crab.

43. The lower Columbia River supports very large runs of fish which are valuable both to recreational and commercial interests. These fish include salmon, steelhead, sturgeon, and shad. In addition to the finfish, the nearshore area adjacent to the Columbia River mouth supports an extremely active commercial dungeness crab fishing fleet.

Entrance Channel Sediment Characteristics

44. Sediments typically dredged from the entrance channel consist of well-sorted fine to medium sand particles having a median diameter of about 2.5 ϕ. Combined clay and silt fractions of these sediments generally represent less than 3 percent of the total. Chemically, these sediments are relatively clean and free of pollutants. The tabulation below summarizes total metal chemistry (dry weight) of 5 surface sediment samples taken within the entrance channel during June 1975:

Property	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Cadmium, mg/kg	0.1	BD*	BD	BD	BD
Copper, mg/kg	0.5	0.1	1.3	1.5	0.5
Iron, mg/kg	3500	3400	4000	3800	3100
Manganese, mg/kg	60	63	46	40	24
Zinc, mg/kg	8.3	11.4	10.7	9.9	5.1
Nickel, mg/kg	2.8	5.1	6.0	4.8	4.9
Lead, mg/kg	2.0	2.5	2.0	2.1	1.6
Mercury, mg/kg	0.0066	0.0077	0.011	0.0074	0.0063
Sulfide, mg/kg	BD	BD	BD	BD	BD
Oil and grease, mg/kg	BD	BD	BD	BD	BD
pH	7.8	7.5	7.7	7.5	--
Eh, mV	40	40	40	39	40

* BD denotes below detection.

PART IV: METHODS AND MATERIALS

45. The field study was conducted in four phases: pilot surveys, predisposal sampling, disposal monitoring, and postdisposal sampling. Pilot surveys and predisposal sampling were initiated in August 1974 and continued for approximately 11 months. Disposal operations at the experimental disposal area (area G) were begun in July 1975 and terminated at the end of August 1975. Postdisposal sampling continued through June 1976. In order to provide a more complete description of the field and laboratory studies conducted, a general discussion of each of the study phases is provided below. More detailed information on each aspect of the investigation is provided in Appendices A-E to this report.

Phase I: Pilot Surveys

46. During the initial stages of the field study, the primary effort was directed toward characterization of the physical, chemical, and biological aspects of the nearshore area, testing of sampling equipment, and selection of the experimental disposal area and reference areas. During September 1974, series of preliminary bathymetric, side-scan sonar, and subbottom profiling surveys were conducted in the study area, with particular emphasis on disposal areas B, D, E, and F. In addition, approximately 160 Shipek grab samples were obtained from these same areas for grain-size and mineralogical studies.

47. During late September 1974, two cruises were made to collect water and sediment chemistry data. Water column and suspended fraction samples were collected from several depths at nine stations on one cruise (Figure 4), and box core sediment samples were collected from seven stations on the second cruise (Figure 5).

48. Plankton samples were taken on the same cruises from the same stations as chemical samples. Thirty zooplankton samples were taken at discrete depths from bottom to surface using an onboard hydraulic pump and a No. 6 (0.233-mm mesh) Nitex net. A similar number of

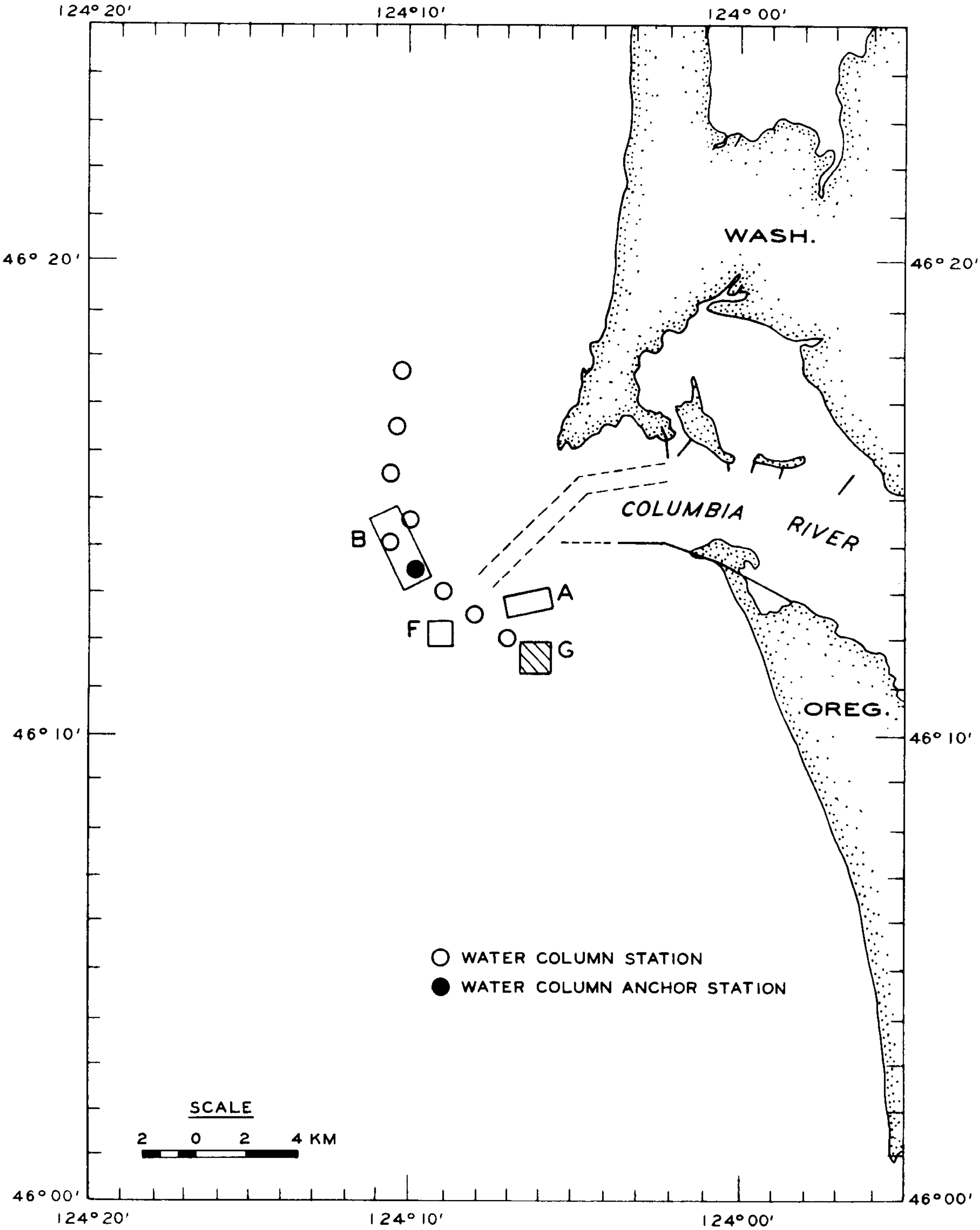

Figure 4. Station locations for pilot survey of water column and suspended fraction; first cruise, September 1974

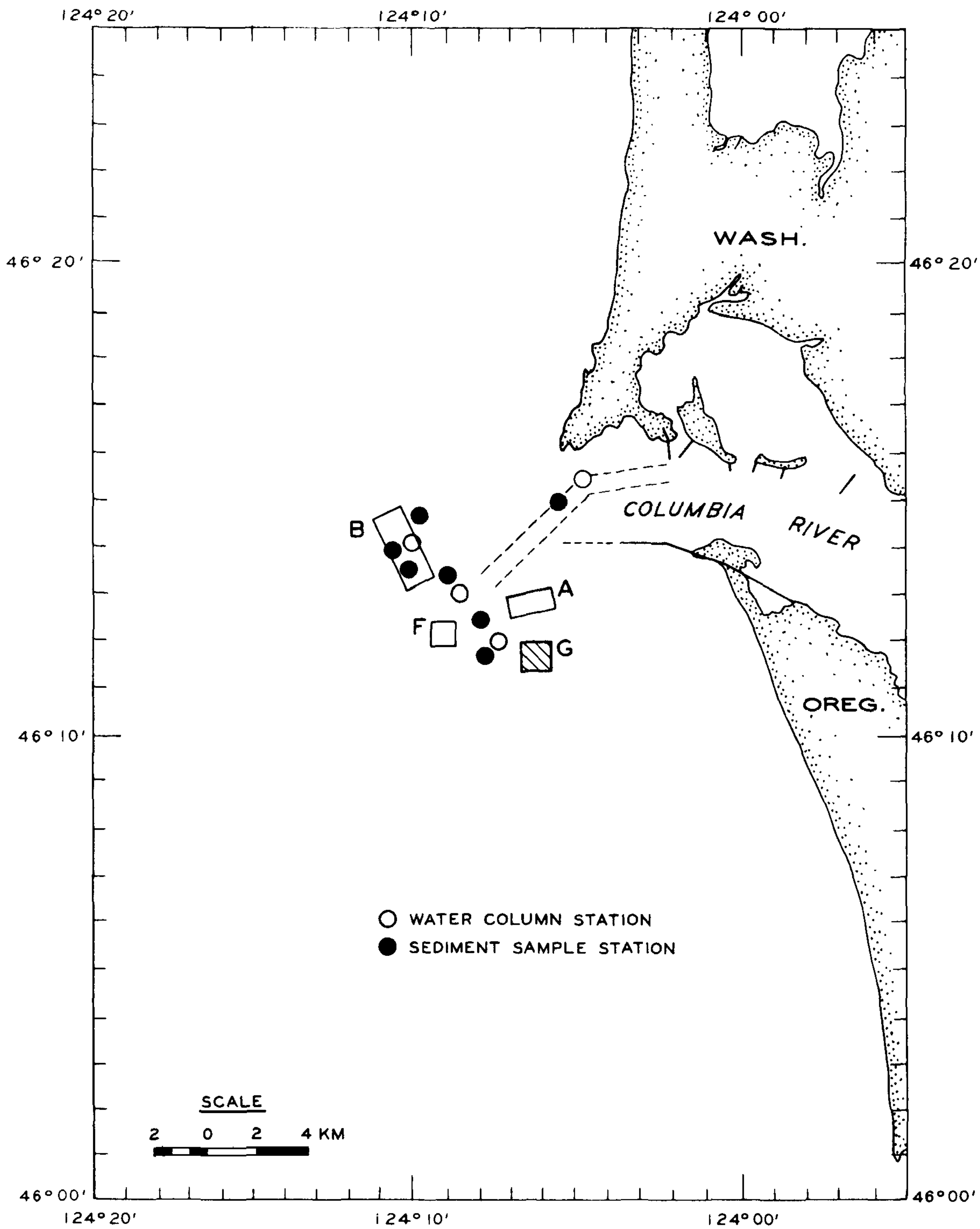

Figure 5. Station locations for pilot survey of sediments; second cruise, September 1974

ichthyoplankton samples were collected with a 1-m net (0.571-mm mesh) from surface, bottom, and oblique tows. In addition, a time series of plankton samples was taken at 2-hour intervals during daylight hours at the water column anchor station in disposal area B (Figure 4).

49. A pilot benthic survey was conducted during early October 1974 to evaluate sampling equipment and to determine species composition and faunal densities. Twenty-one nonreplicated 0.1-m^2 Smith-McIntyre grab samples were obtained from disposal area B (Figure 6), and 25 nonreplicated grab samples were obtained from adjacent areas (Figure 7). These samples were analyzed, and the results were compared with sediment physical and chemical characteristics and used in selecting future benthic sampling locations, strategies, and gear types.

50. Monthly demersal fish and decapod shellfish sampling was initiated during October 1974. Initially, replicate trawls were made with two modified semiballoon shrimp nets with 8- and 5-m headropes from a minimum of two sites in the study area. After May 1975, the 8-m net was used exclusively for replicate tows. Locations of fishery sampling stations are shown in Figure 8.

51. Physical, chemical, and biological data from the pilot surveys were reduced and evaluated prior to selection of the experimental disposal area. Factors considered in this selection process, in no particular order, were:

- a. Differentiation of the area from previous disposal areas.
- b. Water column depth.
- c. Benthic community structure.
- d. Sediment physical and chemical properties.
- e. Susceptibility to influence of the river mouth.
- f. Proximity of dredging site.
- g. Predominant sediment transport rates and directions.

Phase II: Predisposal Sampling

52. Routine collections of physical, chemical, and biological data were made from the fall of 1974 through June 1975 at most of the

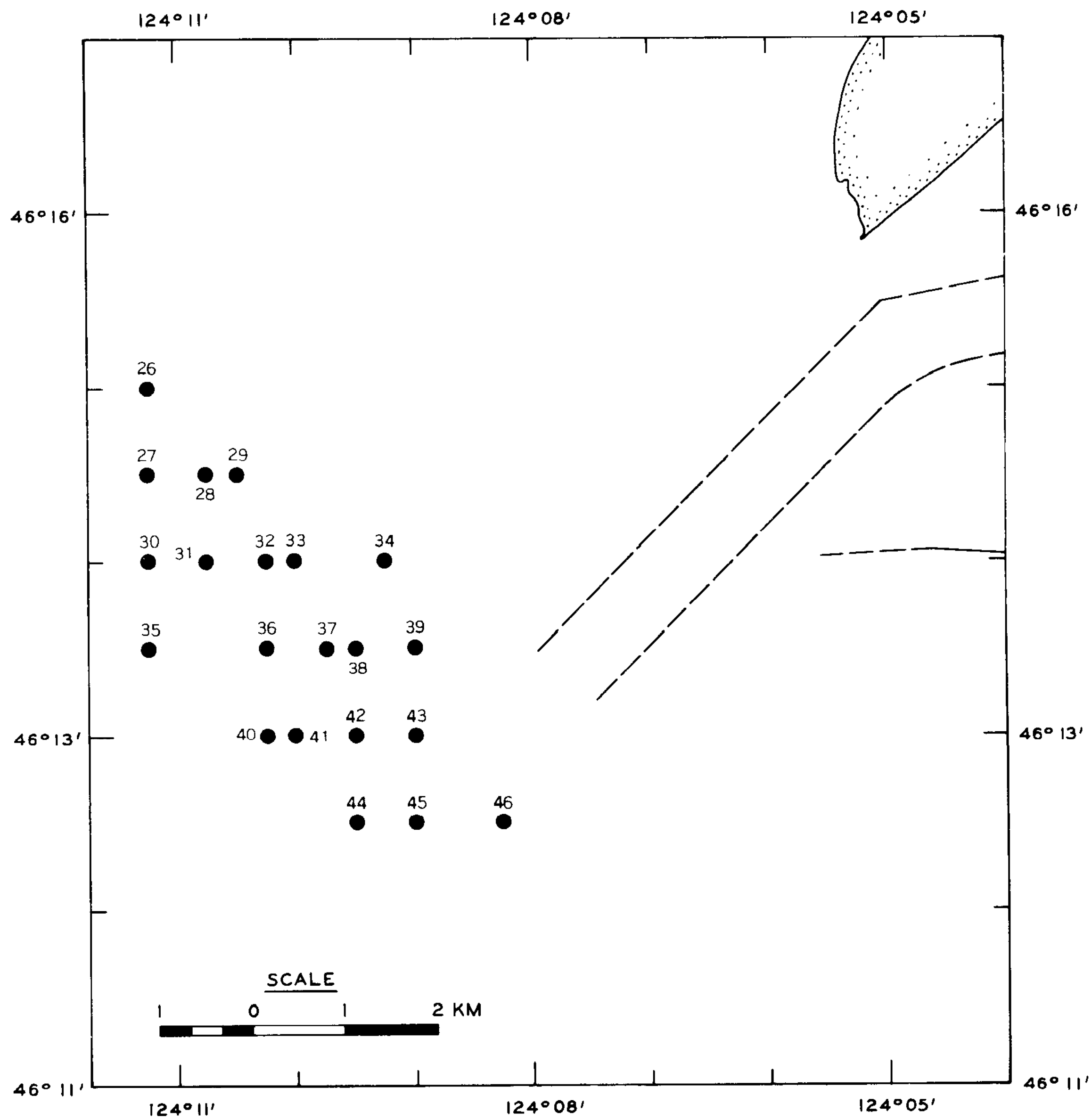

Figure 6. Station locations for pilot survey of benthos in disposal area B, October 1974

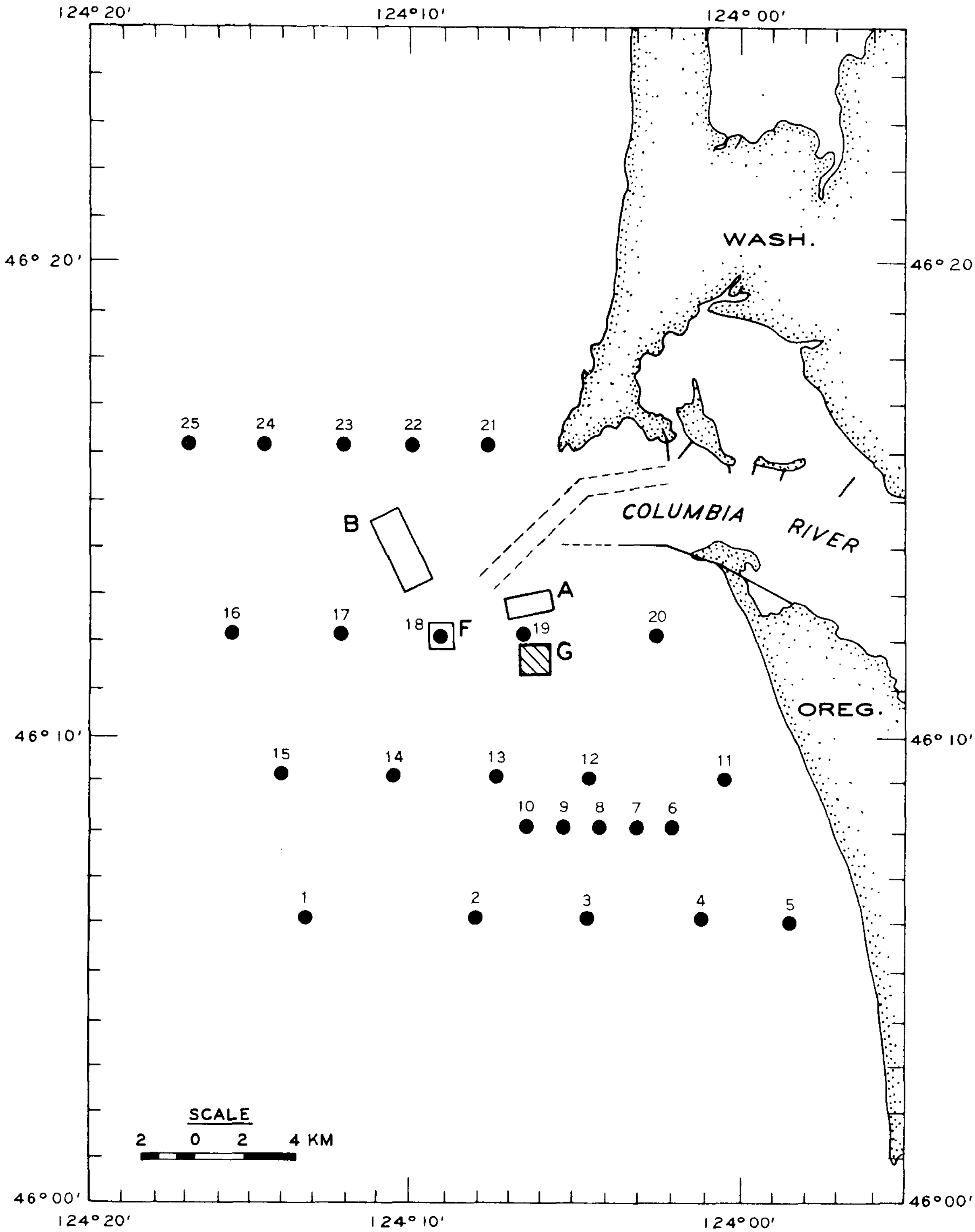

Figure 7. Station locations for pilot survey of benthos in areas adjacent to disposal area B, October 1974

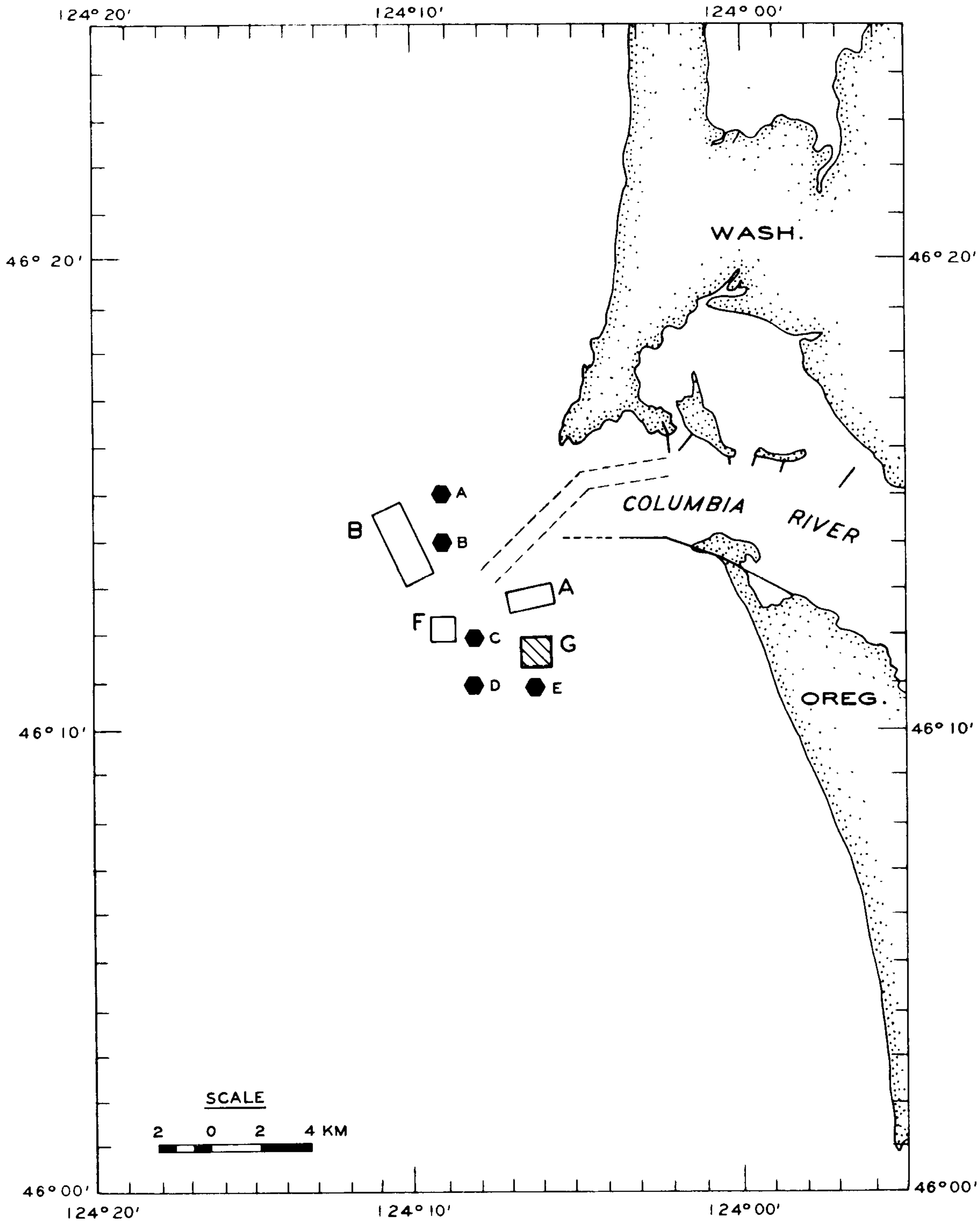

Figure 8. Station locations for pilot survey of demersal fish and decapod shellfish

stations sampled during the pilot surveys. Additional sampling stations were added in the vicinity of the experimental disposal area during June 1975. Physical studies conducted during this phase involved bathymetric, geophysical, geological, and mineralogical sampling and analyses; bottom current measurements; and long-period wave measurements.

53. Bathymetric and seismic profiling cruises were conducted during December 1974 and immediately prior to disposal in July 1975. Instrumented tripod measurements of bottom boundary layer conditions were made in disposal area B and at a reference site approximately 1.8 km to the north between 12 April and 5 May 1975. The instrumented tripods were designed to remain on the seabed for up to 30 days and continuously measure current speed and direction and differential pressure. They were also designed to activate a beam transmissometer every 30 min, recover suspended sediment samples at predetermined particulate concentrations, and take a bottom photograph every 30 min. Sediment samples for determinations of grain size and mineralogy were taken during October, November, and December 1974 and January, April, and June 1975 during this phase of the study. The approximately 280 Shipek grabs collected from the study area during this period were used for grain-size analysis and mineralogic recognition mapping. A bottom-mounted pressure tranducer deployed during this period to measure tides and other long-period waves was not recovered.

54. Aanderaa, fast-response current meters designed to measure wind waves and large-scale turbulent eddies, were deployed in arrays during June 1975 as part of the physical oceanographic study of the area. The arrays were deployed at the ends of the north and south jetties and in disposal area B for a period of 2 weeks to measure peak river discharge. In addition, four conductivity, temperature, and depth (CTD) stations inside the river mouth were sampled for approximately 25 hours each, also during this 2-week period.

55. A box core was recovered for sediment chemistry analysis from each of eight stations during 23-25 January 1975 (Figure 9). Each core was extruded and sectioned into 5-cm specimens. Water column samples for nutrient analyses were pumped from discrete depths at

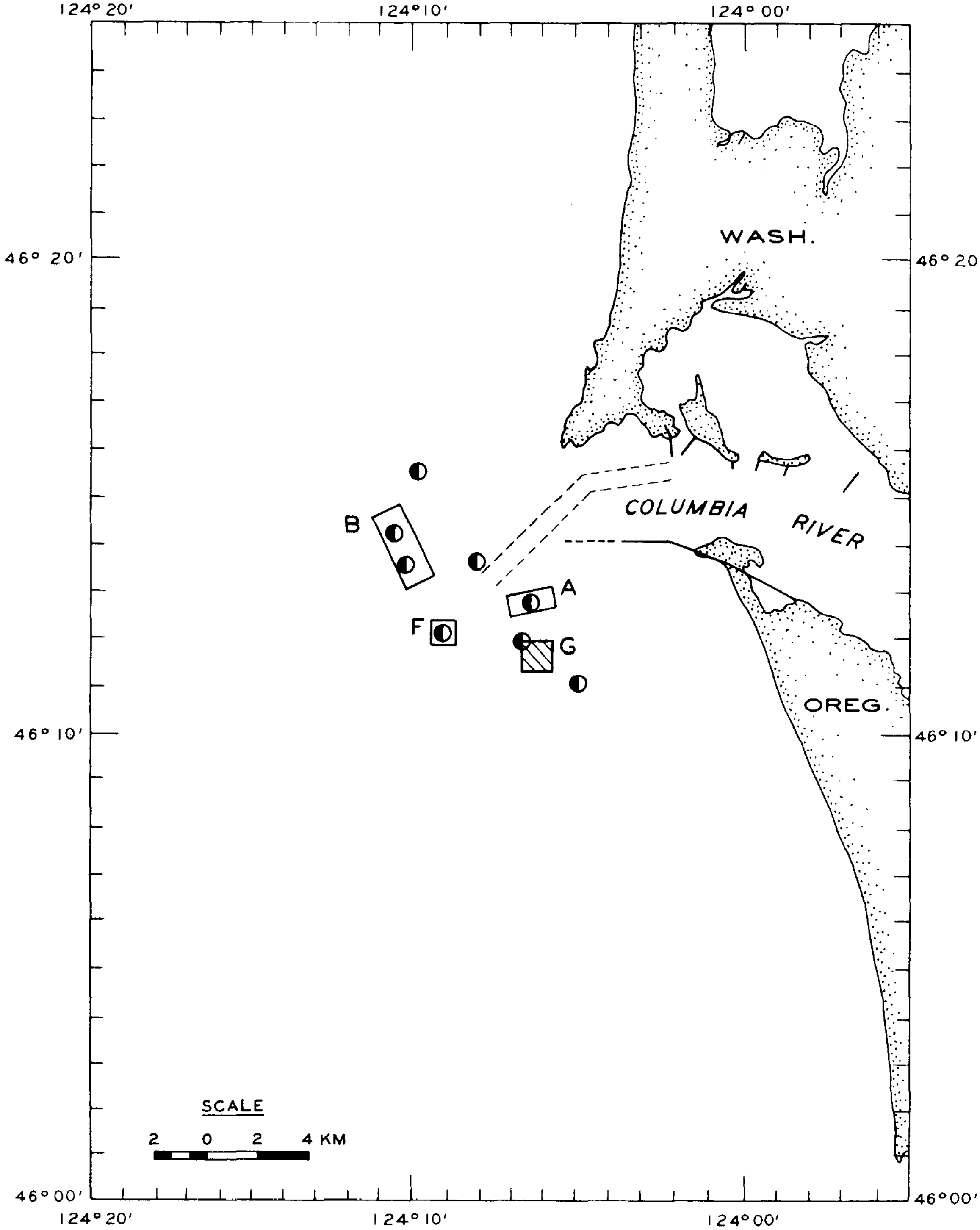

Figure 9. Station locations for predisposal sampling of water column and sediment chemistry, January 1975

the same eight stations at this time.

56. During the last 2 weeks of June 1975, a major chemical survey was conducted in the study area. Two anchor stations were selected for monitoring water column nutrients. One was located in disposal area B, and the other was in the experimental disposal area. At each anchor station, a complete nutrient series was run every 4 hours at several depths over a 30-hour period. Also, five box cores were taken in the entrance channel to characterize the sediments prior to dredging. Finally, water column samples were collected from three depths at two stations in the experimental disposal area for metal analysis.

57. Predisposal samples of benthic invertebrates were collected during December 1974 and January, April, and June 1975. During each cruise, six grabs were taken from each of approximately 50 stations. Five grabs were analyzed for macrofauna, and the sixth was used for sediment grain-size and mineralogy determinations. Metered beam trawls were also made, on a limited basis, when weather conditions permitted.

58. Zooplankton and ichthyoplankton samples were collected in January, March, and June 1975. Surface, bottom, and oblique tows were made using two nets (0.5-m net, 0.233-mm mesh; 1-m net, 0.571-mm mesh) at each station. At the two 30-hour anchor stations monitored during June 1975, tows were made approximately every 4 hours. Also, as part of the June 1975 plankton analysis, potential carbon-14 productivity samples from several depths were incubated at two light levels and in dark bottles. Seven additional in situ incubations were made at one 30-hour anchor station. The effects of introducing various levels of zinc, copper, manganese, and cadmium on the rate of carbon-14 fixation by phytoplankton were also studied during June 1975.

59. Demersal fish and decapod shellfish sampling during the predisposal period consisted of replicated 5-min trawls from four stations. Surface and bottom salinity and temperature measurements were made at the beginning and end of each tow. Fish and shellfish samples were collected during November 1974 and January, March, April, May, and June 1975. Stomach content and food habit studies were conducted on selected dominant species beginning with samples in January 1975 and

continuing throughout the remainder of the study.

Phase III: Disposal Monitoring

60. Disposal of dredged material at the experimental area began on 9 July 1975 and terminated on 27 August 1975. Approximately 459,000 m^3 of dredged material was dumped there. The area was marked by the U. S. Coast Guard with a special purpose buoy during the first week of July. For the first month of the disposal operation, both dredges BIDDLE and HARDING deposited materials at the area. After 3 August 1975, only the HARDING continued to deposit material at the area.

61. Daily hopper dredge bin samples were recovered for grain-size analyses. Two instrumented tripods were deployed in the vicinity of the disposal area to measure bottom boundary layer conditions during disposal. It was decided to delete other experimental hydraulic studies which included salinity, temperature, and depth (STD) profiling in the river and the deployment of fast-response current meters.

62. Chemical studies during disposal were limited to metal and nutrient analyses of the water column. No sediment samples were taken during this phase of the project. Replicate (two bottles at each depth) hydrocasts at three depths were made immediately prior to and just after the initiation of disposal operations for metal analyses. On a second cruise near the termination of disposal operations, a 30-hour anchor station was established and monitored for water column nutrients and STD. This same station was also monitored for the same water column properties for 12 hours following the last hopper dredge load.

63. No benthic samples were taken during the disposal operation. However, one 30-hour plankton station was established at the disposal area prior to disposal. During disposal, the same anchor station was monitored for 12 hours. The same anchor station was monitored for zooplankton and ichthyplankton for 30-hours near the termination of the disposal experiment.

64. Demersal fish sampling during this phase consisted of replicate trawls from four locations prior to disposal in early July and

during disposal in July and August 1975.

Phase IV: Postdisposal Sampling

65. Physical studies following disposal consisted of detailed bathymetric, side-scan sonar, and subbottom profiling surveys at the experimental disposal area immediately after disposal. Bathymetric changes would serve as a basis for determining the size and shape of the disposal mound. Other physical studies during this phase consisted of the collection of sediment samples for grain-size and mineralogy studies during September, October, and December 1975 and January, April, and June 1976. Hydraulic studies were limited to the deployment of two tripods, one at disposal area B and one at the experimental disposal area for a 26-day period from 12 December 1975 to 6 January 1976. Bathymetric surveys were conducted at the experimental disposal area immediately after disposal in September 1975 and again during January, February, and March 1976.

66. Postdisposal data were collected from the experimental disposal area and reference area to evaluate the extent and duration of the impact of disposal on the nearshore benthic and demersal communities. Primary emphasis during this phase was on the impact on the benthos and their ability to recolonize the disposal area. The mechanics of sediment transport in the vicinity of the disposal area was also evaluated.

67. Six weeks following termination of disposal operations, a chemistry/plankton cruise was completed. Replicated box cores were taken from three stations in the experimental disposal area and three reference stations. Hydrocasts for near-bottom dissolved and particulate metals samples were taken at four stations. Water column nutrient samples were pumped from the bottom at the experimental disposal area for a 30-hour period. Two additional water column nutrient stations (one north and one south) were sampled for 24 to 26 hours. Zooplankton and ichthyoplankton net tows were made at each of the above anchor stations about every 4 to 5 hours.

68. Benthic sampling following termination of disposal was conducted during October 1975 and January, April, and June 1976. April and June sampling was restricted to 12 stations in the immediate vicinity of the experimental disposal area.

69. Demersal fish sampling was conducted during September, November, and December 1975 and January, February, and April 1976 following disposal.

Study Variables

70. Five contractors participated in the field studies. The results of their studies can be found in Appendices A-E to this report. For the convenience of the reader, a listing of the physical, chemical, and biological field and laboratory methods and procedures is given in Table 3.

Table 3

Field and Laboratory Methods Used in the Collection and Analysis of Physical, Chemical, and Biological Data

Variable	Procedure/Method
PHYSICAL VARIABLES	
Field	
Station location	Del Norte Trisponder
Bathymetry	Atlas echo sounder, 200 kHz
Subbottom profile	Ocean sonics, 3.5 kHz
Side-scan sonar profile	EG&G, 105 kHz
Current speed, direction, pressure, transmission, bottom photograph	Instrumented tripod/Savonius rotor, Montedoro-Whitney transmissometer
Wind waves, eddy movements	Aanderaa current meter arrays
Suspended fraction character	In situ collection from water bags on instrumented tripod
Salinity, temperature, depth	CTD profiling
Sediment character	Shipek grab
Laboratory	
Grain size	Sieve/pipette
Minerology	X-ray diffraction, X-ray fluorescence, magnetic/non-magnetic ratios, point counting/mineral indices
CHEMICAL VARIABLES	
Field/Laboratory (Water Column)	
(Nutrients)	
Sample collection	STD--pumping system
Station location	Radar--range, Del Norte Trisponder
Temperature	Bisset Berman 9040 STD
Salinity	STD
Density	STD

(Continued)

Table 3 (Continued)

Variable	Procedure/Method
(Nutrients) (Continued)	
In situ light	Lambda instruments quantum sensor
NO_3, NO_2, PO_4, SiO_3, NH_3	Auto-analyzer from pumped sample
Total available phosphorus	UV irradiation followed by analysis of PO_4
Particulate carbon and nitrogen	Carlo Erba CHN-O elemental analyzer
pH	Dow-Corning combination electrode
O_2	Winkler O_2
Chlorophyll a, b, c, phaeophytin A	Colorimeter
Primary production	Incubations--light/dark bottles
Urea	Auto-analyzer
(Metals)	
Collection	Teflon-lined NIO bottles
Mn, Cu, Zn, Cd, Fe, Hg, Ni, Pb (dissolved and particulate)	APDC--chloroform extraction, AAS
Field/Laboratory (Sediment Sampling)	
(Sediments)	
Station location	Radar--range, Del Norte Trisponder
Sample collection	Bouma box corer
pH, Eh	Beckman meter
Total organic carbon	CHN analyzer
Total organic nitrogen	CHN analyzer
Ammonia	Acidified NaCl extraction--auto-analyzer
Total phosphorus	UV digestion
Oil and grease	Soxhlet extraction
Cation exchange capacity	Sodium acetate--$MgCl_2$ washing followed by AAS for Mg

(Continued)

Table 3 (Continued)

Variable	Procedure/Method
	(Sediments) (Continued)
Sulfide	Iodometric
Ni, Fe, Mn, Cu, Zn, Cd, Pb	Acid leaching--AAS
Hg	Nitric acid digestion--flameless AA
Percent water	Gravimetric
	(Interstitial Water)
Sample collection	Reeburgh-type extractor on subsamples from cores
Cd, Cu, Fe, Mn, Ni, Zn, Pb	AAS
NO_3	Auto-analyzer
Orthophosphate	Auto-analyzer
Silicate	Auto-analyzer
Total nitrogen	UV digestion
Total phosphorus	UV digestion
Ammonium	Auto-analyzer
	BIOLOGICAL VARIABLES
	Field
Macrobenthos	0.1-m^2 Smith-McIntyre grab
Epibenthos	Beam trawl
Station locations	Del Norte Trisponder
Phytoplankton	10-μ net sieve
Zooplankton	Plankton net (0.233- and 0.110-mm mesh)
Ichthyoplankton	Plankton net (0.571-mm mesh)
Station locations	Radar--range
Demersal finfish and shellfish	Semiballoon trawl (8 and 5 m)
Station locations	Radar--range
	Laboratory
Macrobenthos	1.0-mm screen, sorting, identification, enumeration, biomass

(Continued)

Table 3 (Concluded)

Variable	Precedure/Method
	Laboratory (Continued)
Epibenthos	Sorting, identification, enumeration
Phytoplankton	Carbon-14 production, potential productivity, identification
Zooplankton	Sorting, identification, enumeration
Ichthyoplankton	Sorting, identification, enumeration

PART V: RESULTS AND DISCUSSION

Physical Studies

General nearshore characteristics

71. Bathymetry. Regional bathymetric survey data for several years were reduced and compared to determine the nature and magnitude of changes occurring at the study area. Examination of bathymetric changes occurring over 1-year periods (1964-1965 and 1965-1966) indicated that there was no systematic erosion or deposition in the nearshore zone adjacent to the Columbia River mouth. However, when time periods of 3 to 7 years were considered, there was a tendency for the southern portion of the tidal delta to undergo net erosion while the northern portion was extended towards the north through net deposition. These general patterns agree with those observed by Lockett,[16] who studied offshore scour and shoal volumes between 1926 and 1958.

72. Bathymetry of the study area, based on September 1974 survey data, is shown in Figure 10. It can be seen that the outer tidal delta is skewed to the north, presumably due to the net northerly longshore transport system. This depositional area extends seaward to the 30-m isobath where it forms a steep slope. A secondary bathymetric feature can be observed on the tidal delta directly off the river entrance in the vicinity of disposal area B. This feature ranges in depth between 22 and 36 m and contains an estimated 7,454,000 m^3 of sediment. This estimate was obtained by extrapolating the regional contours through disposal area B, using the average slope calculated from adjacent areas.

73. Tidal currents and near-bottom circulation. Measurements were made with the instrumented tripods deployed north of the river mouth in the vicinity of disposal area B for 24 and 25 days, respectively, between 12 April and 6 May 1975 and 12 December 1975 and 6 January 1976. During the April-May deployment, currents measured 1 m off the bottom had speeds of generally less than 20 cm/sec and exhibited strong tidal variation. Peak current speeds in excess of 65 cm/sec were observed during a 3-day storm towards the end of this deployment period (see

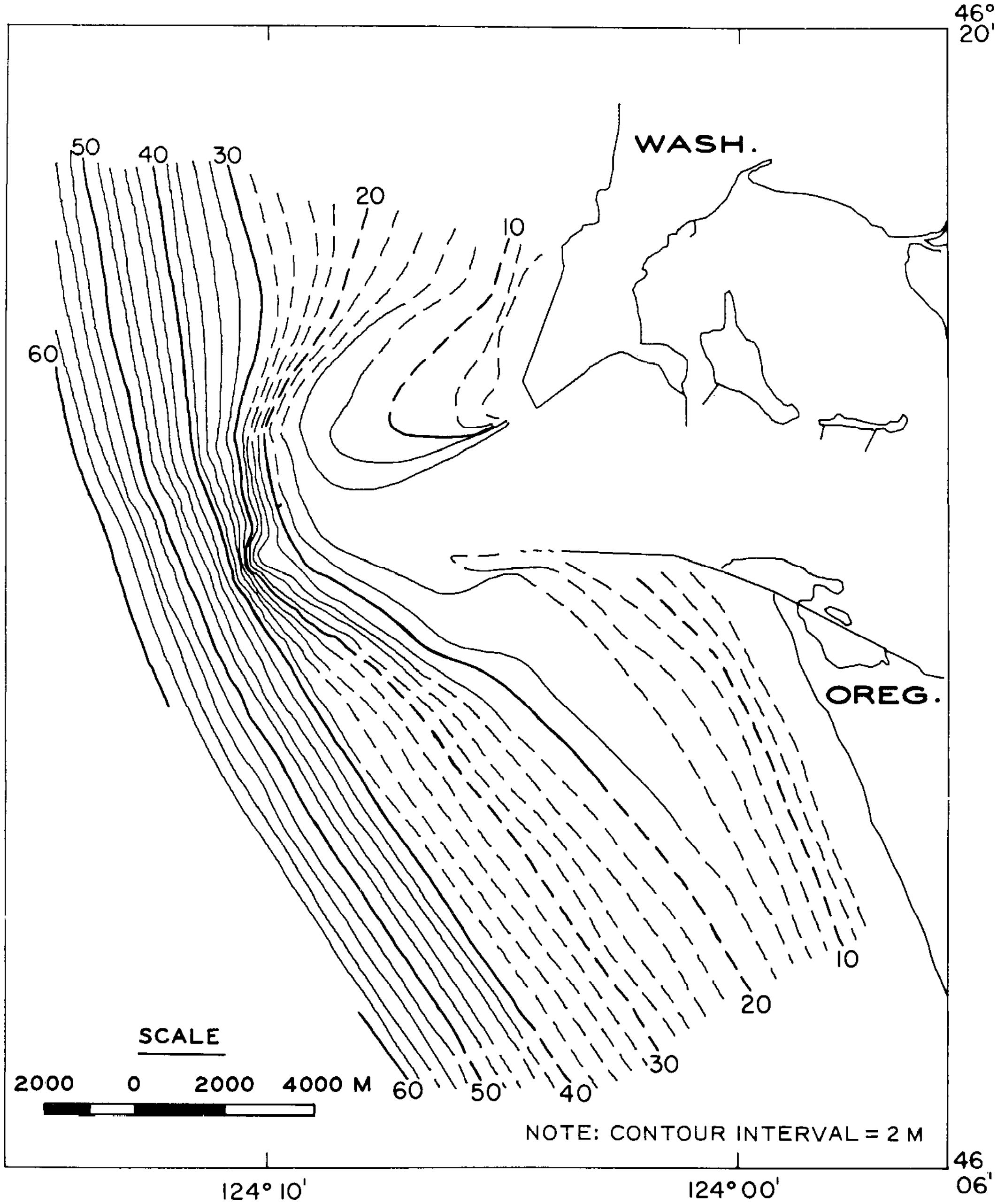

Figure 10. Bathymetry at the study area based on September 1974 survey

Appendix A, Figure A30). Net nontidal bottom flows at disposal area B (tripod station 1) exhibited a northwesterly trend and had speeds which averaged 8.4 cm/sec at 300°T, which parallels the isobaths. About 1.8 km north of disposal area B (tripod station 2), bottom current speeds averaged 3.8 cm/sec at 354°T. The isobaths at this station were oriented at 348°T.

74. During the December-January tripod deployment at disposal area B, bottom current speeds averaged about 30 cm/sec with significantly higher speeds occurring during storm periods. Bottom current speeds as high as 80 cm/sec were recorded during this deployment. Winds speeds of 17.5 m/sec and wave heights of 8.5 m were measured during this same storm period. Nontidal bottom flows were either southerly or westerly during the first 11 days of the record and then shifted to the north in response to the strong southerly winds.

75. River hydraulics. River flow characteristics in the vicinity of the river mouth were found to be very complex both in space and time. Bottom currents in the vicinity of the river mouth associated with the intrusion of denser seawater were observed to fluctuate in diurnal, semidiurnal, and higher frequency modes depending upon the magnitude of river discharge. Bottom current records for periods of maximum river discharge, during stratified estuarine conditions, were observed to be the most complex. This can probably be explained by separation of dilute surface waters and entrainment of denser water from the salt wedge. During periods of minimum discharge, the estuary was more homogeneous, both vertically and horizontally, and bottom flows were less complex, being primarily semidiurnal.

76. Current velocity records are plotted as vector representations in Figure 11 for stations located at disposal area B and the north and south jetties for the period 9-20 June 1975. Maximum currents at all stations generally coincided with times of high and low tide. Currents at disposal area B exhibited a dominant semidiurnal component with speeds reaching 30 to 40 cm/sec on the flood and 90 cm/sec on the ebb. During the sampling period, there was a net southerly flow at this station. Tidal currents measured at the north and south jetties were very

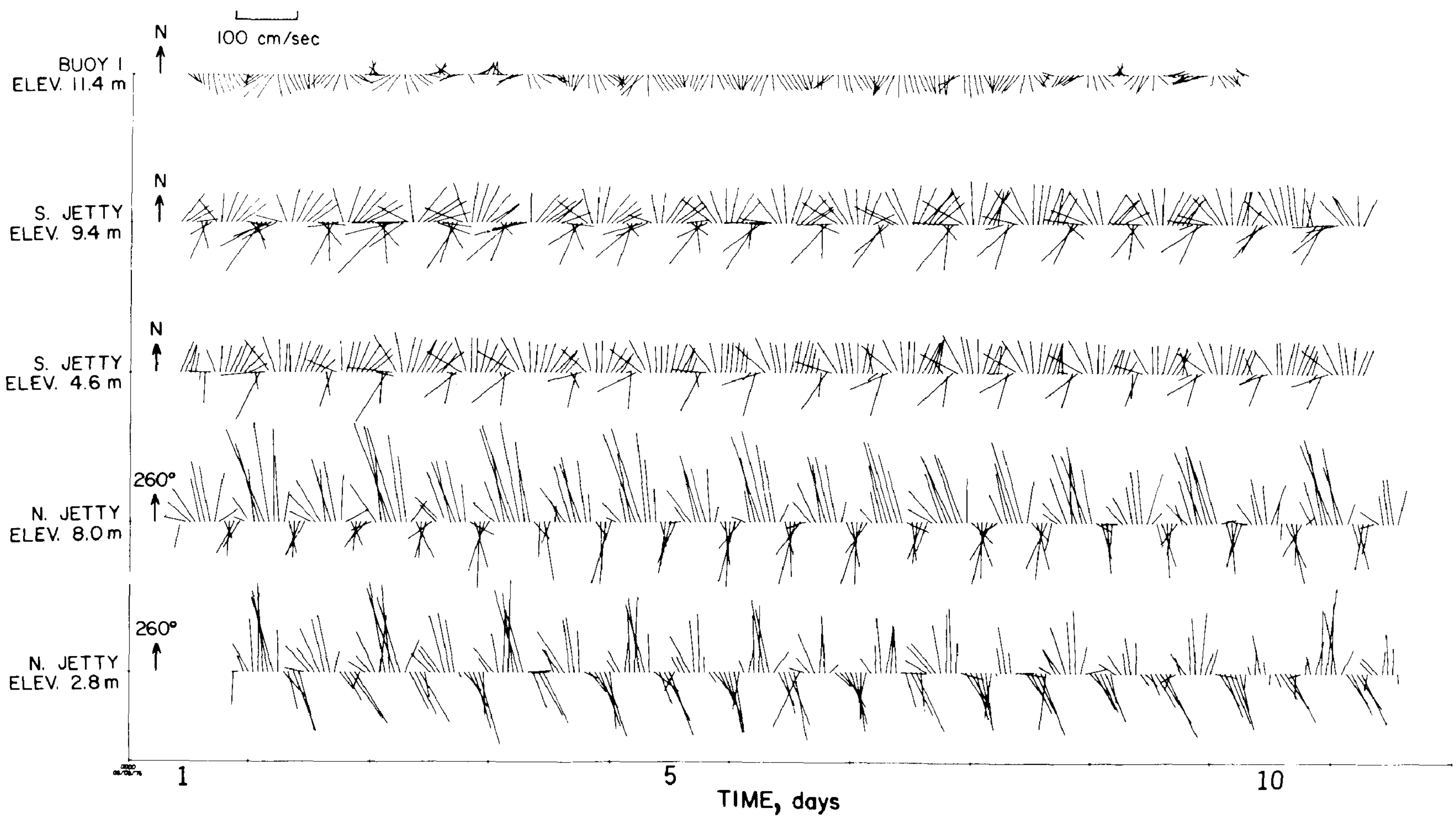

Figure 11. Vector representations of 1-hour time averages of current meter velocities measured at disposal area B (buoy 1) and the north and south jetties. Note that the orientation of the vectors for the north jetty data were rotated 100° counterclockwise to coincide with the river flow direction

much stronger (150 to 200 cm/sec) than those observed offshore. Vector plots show that the bottom flow near the south jetty was predominantly northward, indicating salt wedge intrusion. Closer to the surface, a more pronounced ebb or southward flow was observed. Currents at the south side of the channel tended to show an overall flood dominance, and the zone of maximum salt wedge intrusion appeared to be at the south side of the channel. Examination of vector plots of currents at the north jetty suggests that flow both near the bottom and in the surface layer varied on a tidal basis, with the ebb currents flowing 260°T and flood currents flowing 60°T. Net flows were seaward both near the bottom and in the upper layers. Near-surface flows showed the strongest ebb dominance indicating that the river flows seaward along the north side of the channel.

Sediment texture

77. Sediment samples collected from the study area were subjected to routine sieve (0.25-ϕ intervals for sand fractions) and pipette (0.5-ϕ intervals for silt sizes and 1.0-ϕ intervals for clay sizes) analyses. Textural data were subjected to a Q-mode factor analysis with final oblique rotation. In the analysis, the 29 grain-size classes (0 to 12 ϕ) were used as variables to determine the relationships among samples. Seven factors, which explained 99 percent of the variability among samples, were selected and represented by extremal samples. (A more detailed discussion of this method of analysis can be found in Appendix A, Part IV.) The textural composition of these seven extremal samples is shown in Table 4. The distributions of factor loadings for each of these extremal grain-size distributions are shown in Figures A79-A89 of Appendix A. Factor 1 type sediment, the coarsest-grained material in the study area, had a 2.0-ϕ mode. The distribution of this sediment was primarily restricted to sites of dredged material disposal and the main river channel. Factor 2 sediment, having a 2.5-ϕ mode, was distributed in close association with factor 1 and 3 sediments in patches along the southern edge of the tidal delta and also within the river channel. This type sediment is thought to consist of the coarsest fraction transported as bed load in significant quantities across the tidal delta.

Table 4

Textural Data for Extremal Samples of Each Factor

		Percent Particles of Cited Size, ϕ Units																							
		Sand Fraction												Silt Fraction								Clay Fraction				
Factor	Sample	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00
1	C7409-154	1	1	6	17	32	19	11	6	2	1															1
2	C7411-32			1	4	13	16	47	9	3	2	1	1													1
3	C7409-19					1	5	15	32	24	11	2	1		1	1										3
4	C7409-149					1	1	2	8	15	32	18	10	4	5	1							1		1	1
5	C7411-60			1	3	8	8	7	6	5	8	5	28	14	3											1
6	C7411-86								1	1	3	5	5	4	42	13	7	3	2	2	1	1	1	2	1	4
7	C7409-43			1	1	1	1	1	2	2	3	2	1	1	2	9	8	5	8	8	5	6	7	7	6	12

Note: Values have been rounded to nearest whole percent.

Factor 3 (2.75-ϕ mode) and Factor 4 (3.25-ϕ mode) sediments were the predominant types in the study area. Factor 3 material covered most of the area south of the river entrance and extended northward both east and west of disposal area B. The finer-grained factor 4 sediment generally occurred north of the river entrance where it was deposited over the steeper northern slope of the tidal delta. Factor 5 (3.75-ϕ mode), factor 6 (4.5-ϕ mode), and factor 7 (greater than 12-ϕ mode) materials were the fine-grained component of the sediment. Factor 5 sediment occurred in significant quantities in only three samples and as a result is not discussed here. Factor 6 and factor 7 sediments, consisting of course silt and fine silt-clay modes, were found to occur mostly north of the river entrance. These grain sizes were not common in the dredged material deposits.

78. Sediments dredged from the river entrance and deposited at disposal area G were also subjected to grain-size and factor analyses. These materials typically were found to consist of well-sorted fine to medium sand particles with a median diameter of 2.5 ϕ (predominantly factor 2 sediments). Daily hopper dredge bin samples were taken and subjected to laboratory physical analyses. Factor analysis results on a group of 27 bin samples are shown in the following tabulation:

	Factor Loadings						
Sample No.	Factor 1 2.00- to 2.25-ϕ Mode	Factor 2 2.50-ϕ Mode	Factor 3 2.75- to 3.00-ϕ Mode	Factor 4 3.25-ϕ Mode	Factor 5 3.50- to 4.00-ϕ Mode	Factor 6 4.50-ϕ Mode	Factor 7 12.00-ϕ Mode
H02	0.0652	0.7011	0.4782	-0.0795	-0.0178	-0.0006	-0.0134
H04	0.0042	0.7327	0.4880	-0.1069	-0.0117	-0.0037	-0.0192
H05	0.2783	0.7225	0.2579	0.0164	-0.0359	-0.0194	0.0008
H06	0.0585	0.8229	0.3277	-0.0167	-0.0299	-0.0044	-0.0128
H07	0.2142	0.8379	0.1711	0.0380	-0.0530	-0.0254	0.0032
H08	0.0798	0.8068	0.3442	-0.0651	-0.0241	-0.0025	-0.0123
H09	0.0160	0.6975	0.5159	-0.1010	-0.0105	0.0032	-0.0144
H10	0.0630	0.7463	0.4266	-0.0867	-0.0115	-0.0038	-0.0100
H11	0.1082	0.7336	0.4040	-0.0392	-0.0267	-0.0117	-0.0131
H13	0.5636	0.7141	-0.1359	0.1267	-0.0672	-0.0529	0.0143
H14	0.0975	0.6778	0.4820	-0.0834	-0.0148	-0.0053	-0.0118
H16	0.0978	0.7790	0.3562	-0.0230	-0.0339	-0.0120	-0.0097
H17	0.2081	0.8430	0.1765	0.0086	-0.0462	-0.0207	-0.0021
H20	0.1228	0.5993	0.5391	-0.0481	-0.0192	-0.0111	-0.0196
H21	0.5679	0.7105	-0.1394	0.1442	-0.0745	-0.0532	0.0172
H22	0.2763	0.8819	0.0381	0.0591	-0.0598	-0.0314	0.0049
H23	0.0343	0.6159	0.5910	-0.1055	-0.0073	0.0046	-0.0210
H24	0.1488	0.9575	0.0676	0.0408	-0.0577	-0.0207	0.0053
H27	0.9202	0.2116	-0.0930	0.0807	-0.0290	-0.0605	0.0201
H28	1.0000	-0.0000	0.0000	-0.0000	0.0000	0.0000	-0.0000
H29	0.1877	0.8063	0.2446	-0.0019	-0.0398	-0.0188	-0.0050
H30	0.1331	0.9597	0.0791	0.0512	-0.0603	-0.0250	0.0020
H31	0.1659	0.9131	0.1175	0.0300	-0.0541	-0.0235	0.0006
H32	0.1746	0.6625	0.4285	-0.0116	-0.0325	-0.0166	-0.0137
H33	-0.0092	0.4985	0.7202	-0.1029	-0.0017	0.0050	-0.0281
H34	0.7354	0.4759	-0.0782	0.0784	-0.0405	-0.0507	0.0131
H35	0.4559	0.8550	-0.1970	0.1643	-0.0875	-0.0537	0.0167

79. When seasonal trends were examined, it was found that the greatest change in sediment texture occurred seaward of the river entrance. In general, sediments south of the river mouth exhibited little seasonal change. North of the river entrance, fine sands tended to be covered by silts during the summer months. During the winter months, the silts were either covered by fine sands or resuspended and transported northward.

<u>Sediment mineralogy</u>

80. Columbia River sediments are primarily composed of debris derived from the mechanical weathering of volcanic material of the Cascade Range, with andesite being the single most abundant constituent. Shelf sediments, on the other hand, excluding those in the vicinity of disposal area B, have mineralogic characteristics that are distinct from Columbia River bed material. The primary contrasts in mineralogies are that the shelf sediments contain low abundances of unaltered plagioclase and are rich in either altered lithic fragments or magnetite. The abundances of orthopyroxene and andesitic lithic fragments are also low; however, clinopyroxene, altered plagioclase grains, and basaltic lithic fragments are enriched relative to Columbia River material.

81. Sediment mineralogies were determined primarily by a combination of two methods. In the first, a mineral index (MI), was derived for each sample. This index represents the ratio of fresh plagioclase and potassium feldspar to altered lithic fragments, altered plagioclase, and opaques in the less than $4\text{-}\phi$ fraction of the sample. In the second method, a magnetic ratio (MR) was determined as the ratio of the weight of the nonmagnetic fraction to that of the magnetic fraction, also in the less than $4\text{-}\phi$ fraction. The mineralogical contrasts discussed above were measured using the MI and MR. This method provided a means of estimating systematic or seasonal mineralogic changes on the nearshore shelf as well as determining the fate of dredged material placed at the experimental disposal area.

82. Examination of the spatial trends in mineralogies suggests that there is an initial offshore increase in MI as the magnetite abundance decreases. Seaward of the midshelf, MI values begin to decrease

as the concentrations of altered lithic fragments and altered plagioclase increase. MI values just off the river mouth and at disposal area B were high, indicating the mineralogy of materials derived and/or dredged from the Columbia River. MR values also increased offshore and to the north of the river mouth. Offshore disposal areas had MR values higher than ambient sediments. The behavior of these mineralogic properties results from the fact that magnetite abundance decreased rapidly offshore while the amount of altered lithic fragments increased towards the outer shelf region. These trends were consistent on both sides of the river mouth; however, they were discontinuous in areas where sediments input to the nearshore marine environment by the Columbia River or by dredge material disposal were found.

Experimental disposal area G

83. Bathymetry. Predisposal bathymetry of disposal area G is shown in Figure 12. Bathymetric records of the area indicated that the countours are regular and become shallower to the northeast. Sand waves were present in the area, especially in the northeastern corner of the area surveyed. Water depth at the site of the special purpose buoy was approximately 26 m prior to disposal (7-8 July 1975). The disposal experiment began on 9 July and was terminated on 26 August 1975.

84. Postdisposal bathymetric surveys of the area were conducted on 2-3 September 1975 (Figure 13), 30 January 1976 (Figure 14), 2 February 1976 (Figure 15), and 9 March 1976. During the March 1976 survey, only half of the area was surveyed due to weather conditions, so it will not be further discussed. Isopach maps of the thickness of the dredged material deposits for each postdisposal survey are shown in Figures 16-18. Postdisposal bathymetry indicated that the measurable effect of disposal at area G was confined to a 460-m radius around the special purpose buoy, with accumulation predominantly to the south and west of the buoy. The volume of dredged material on the bottom immediately following the disposal experiment was estimated to be 324,000 m^3, which represents approximately 71 percent of the dredged material reportedly released at this area. This does not imply that 29 percent of the material released did not make it to the bottom; however, it does suggest that inaccuracies

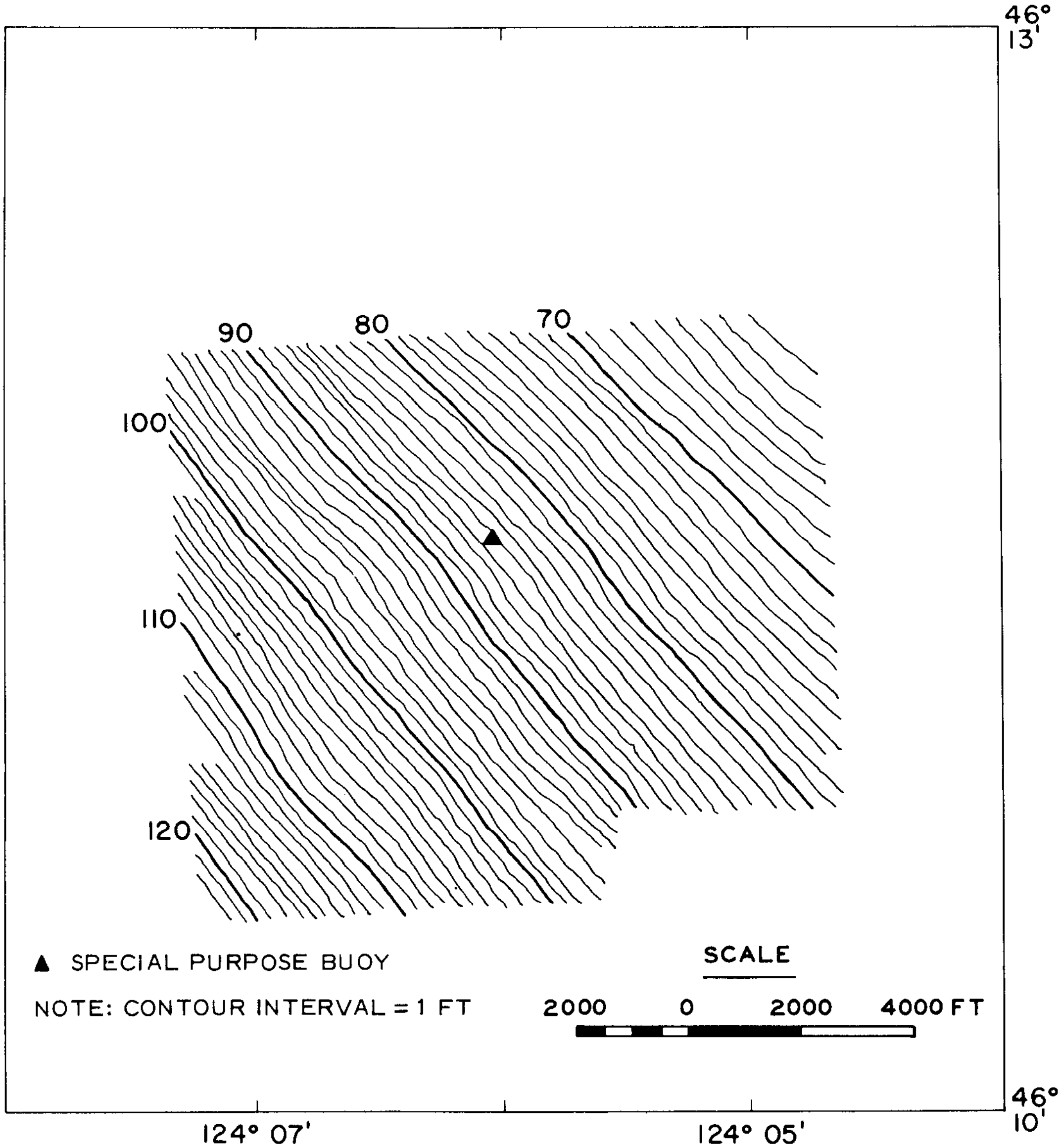

Figure 12. Predisposal bathymetry at area G as of 7-8 July 1975 (multiply feet by 0.3048 to obtain metres)

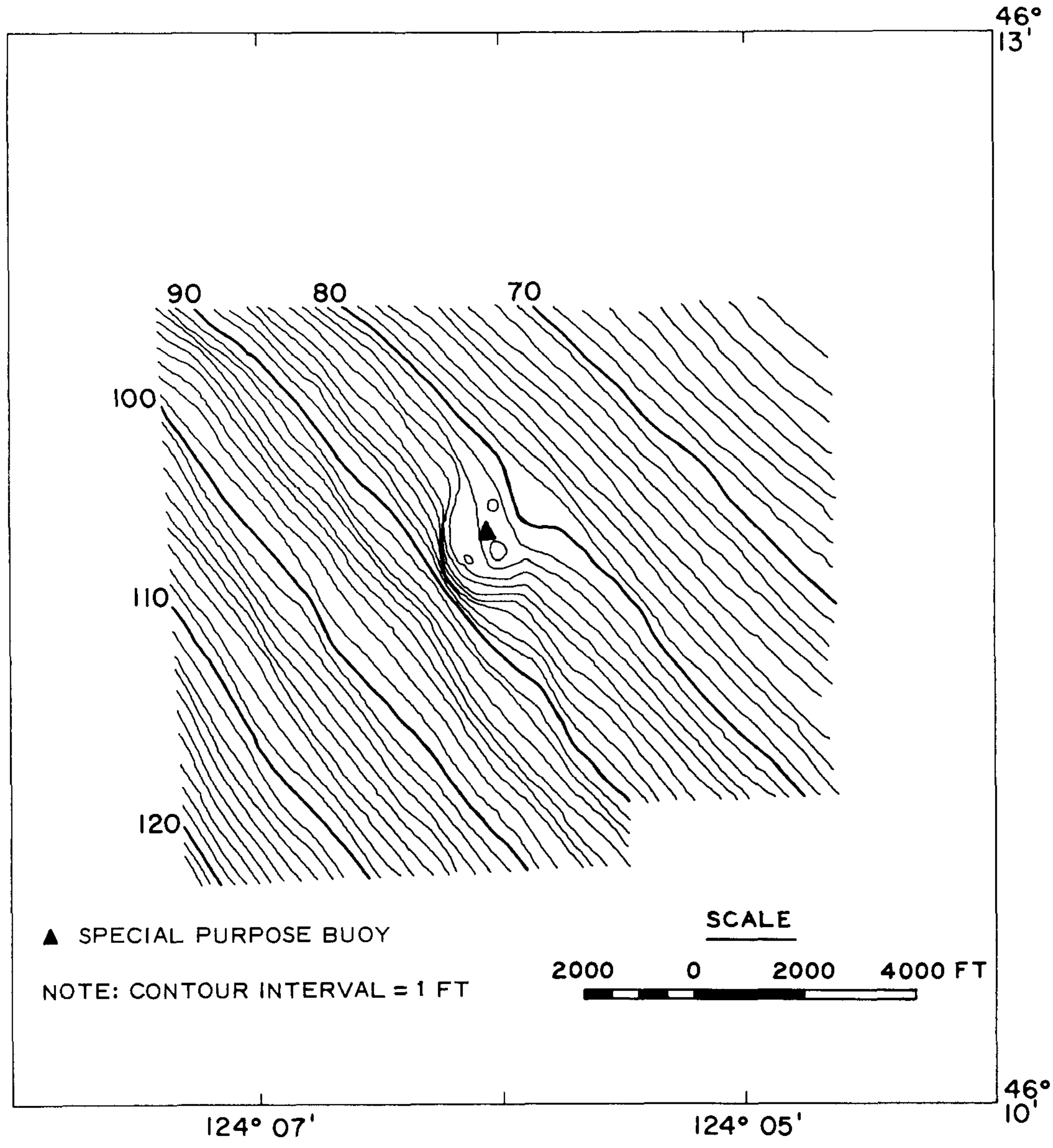

Figure 13. Postdisposal bathymetry at area G as of 2-3 September 1975

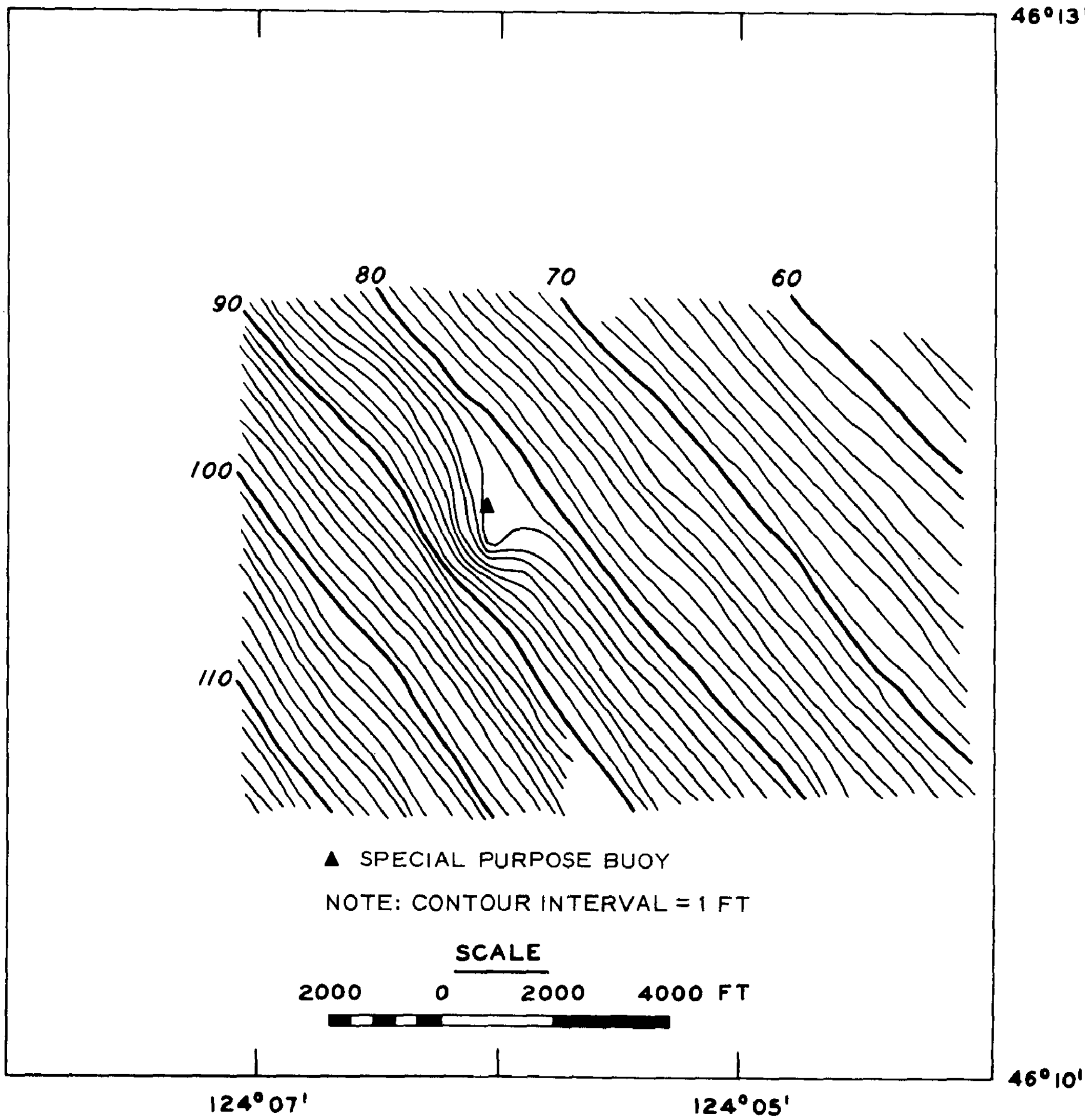

Figure 14. Postdisposal bathymetry at area G as of 30 January 1976

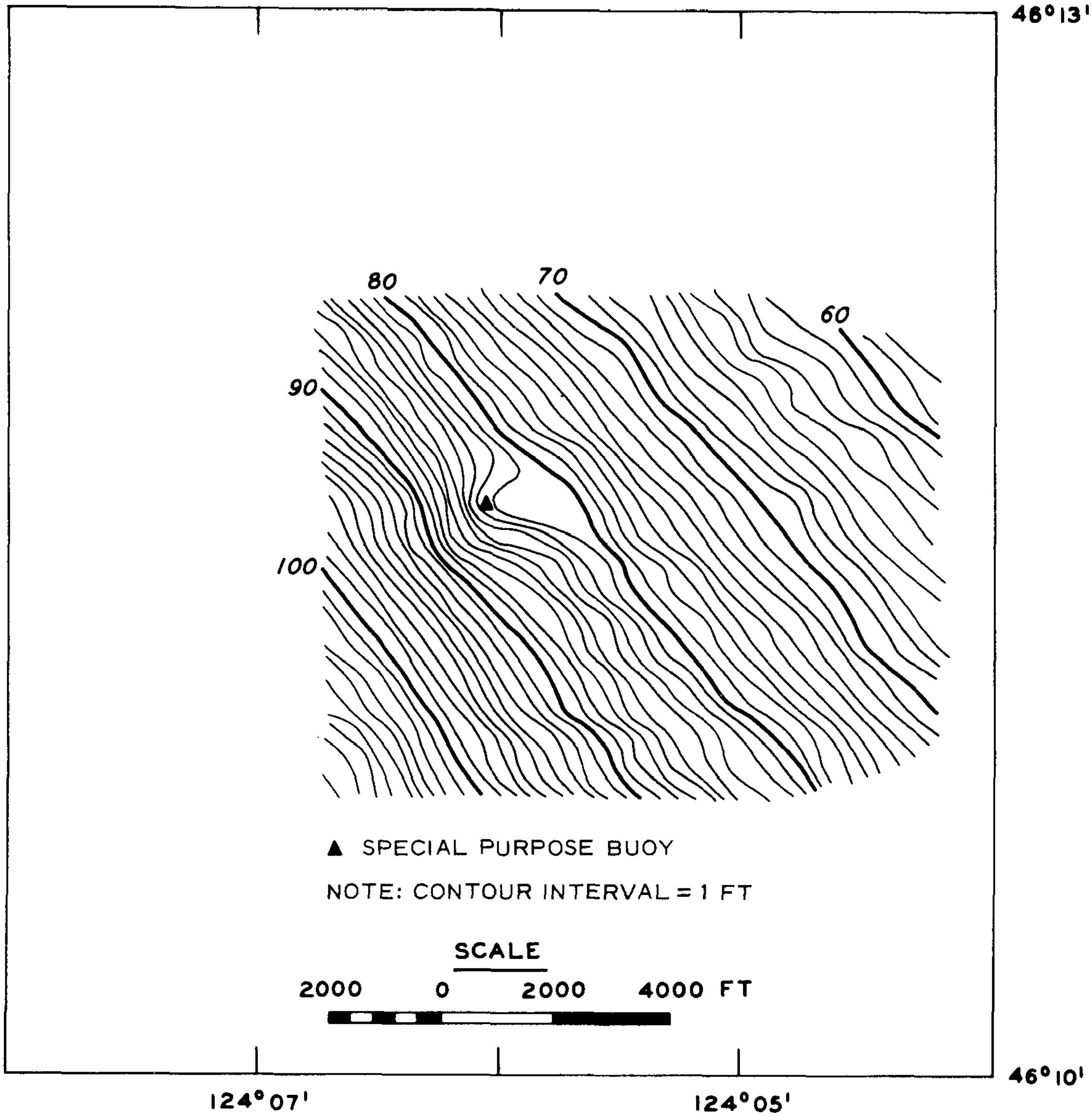

Figure 15. Postdisposal bathymetry at area G as of 2 February 1976

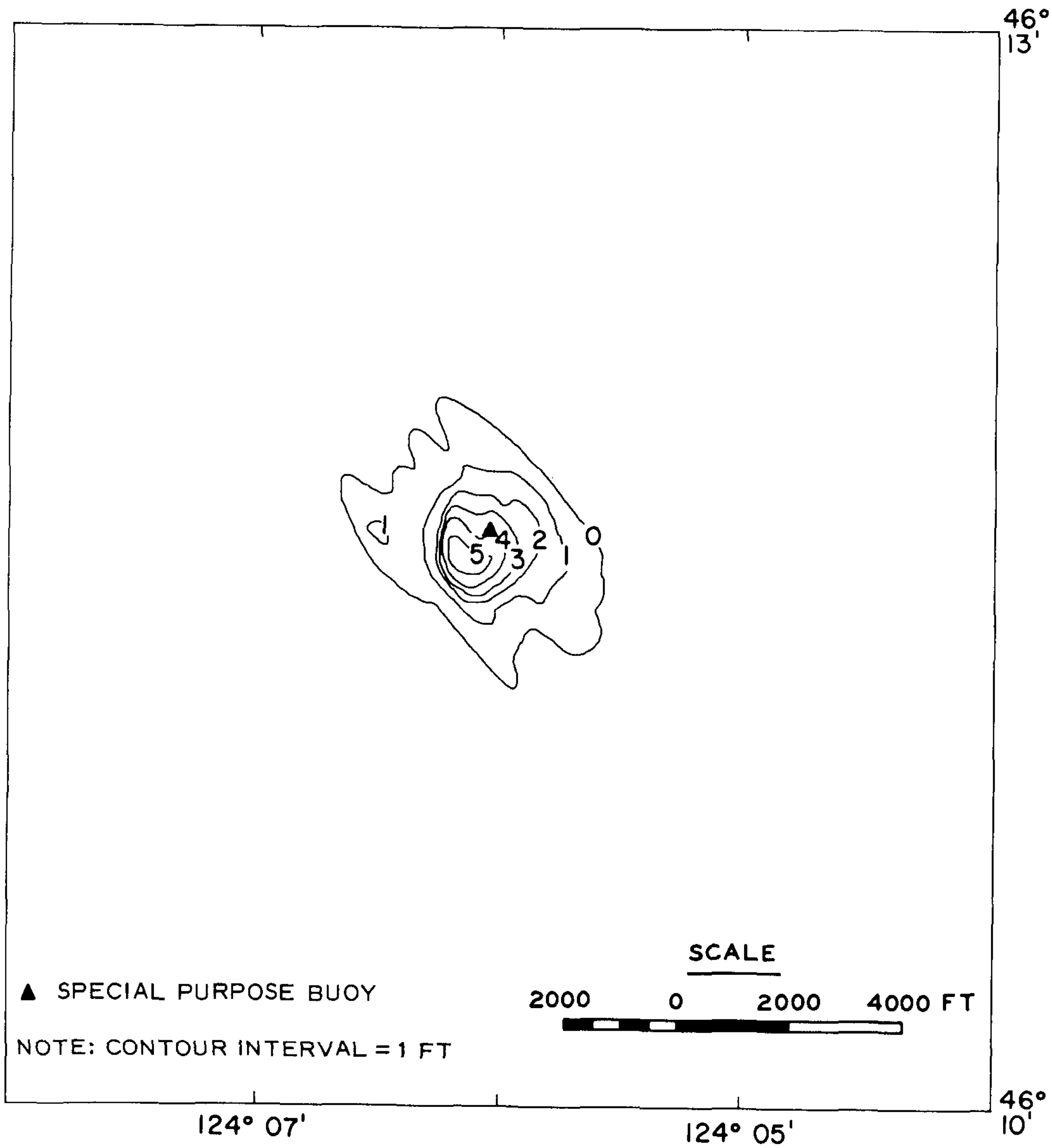

Figure 16. Bathymetry change at area G as of 2-3 September 1975

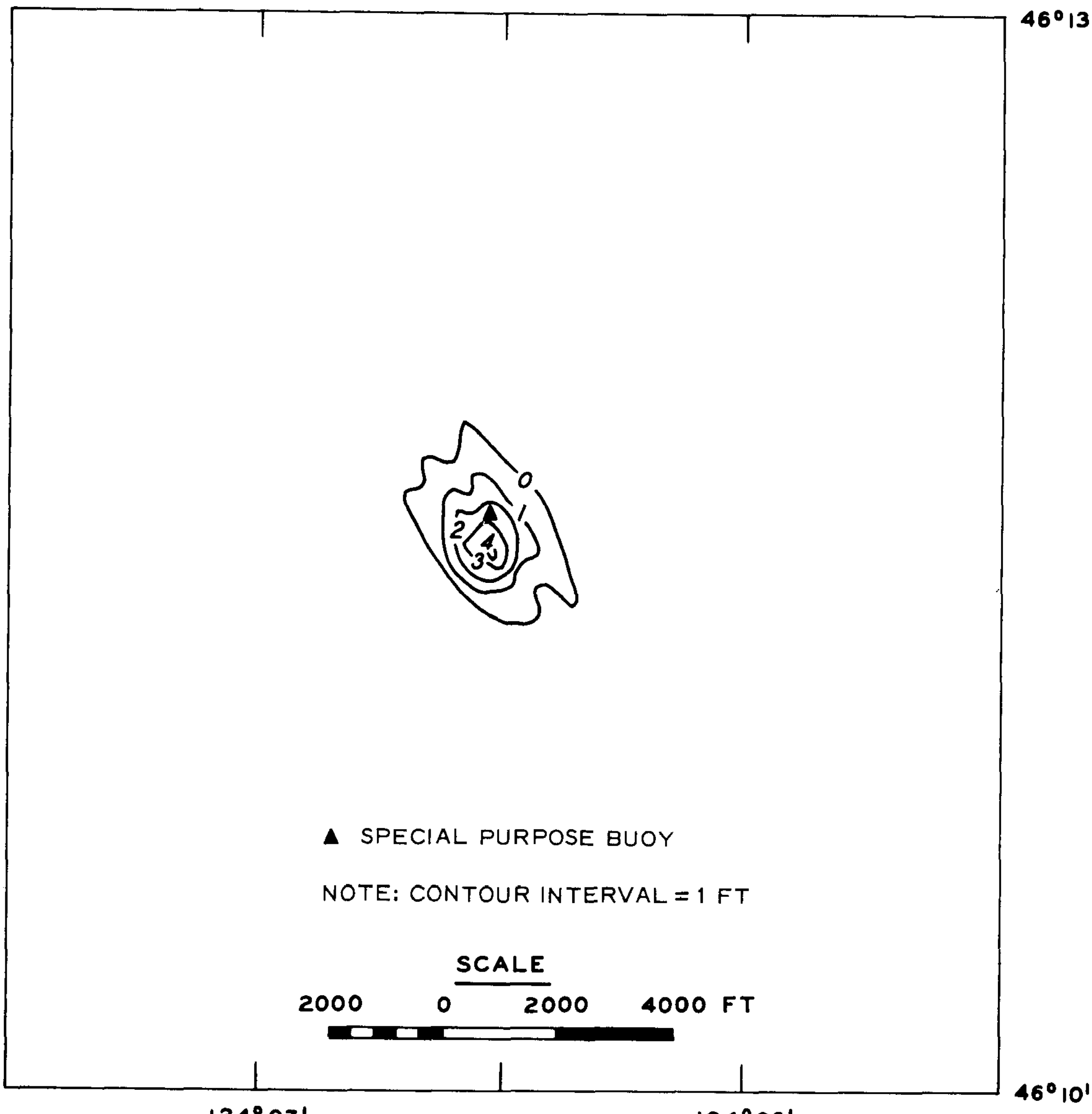

Figure 17. Bathymetry change at area G as of 30 January 1976

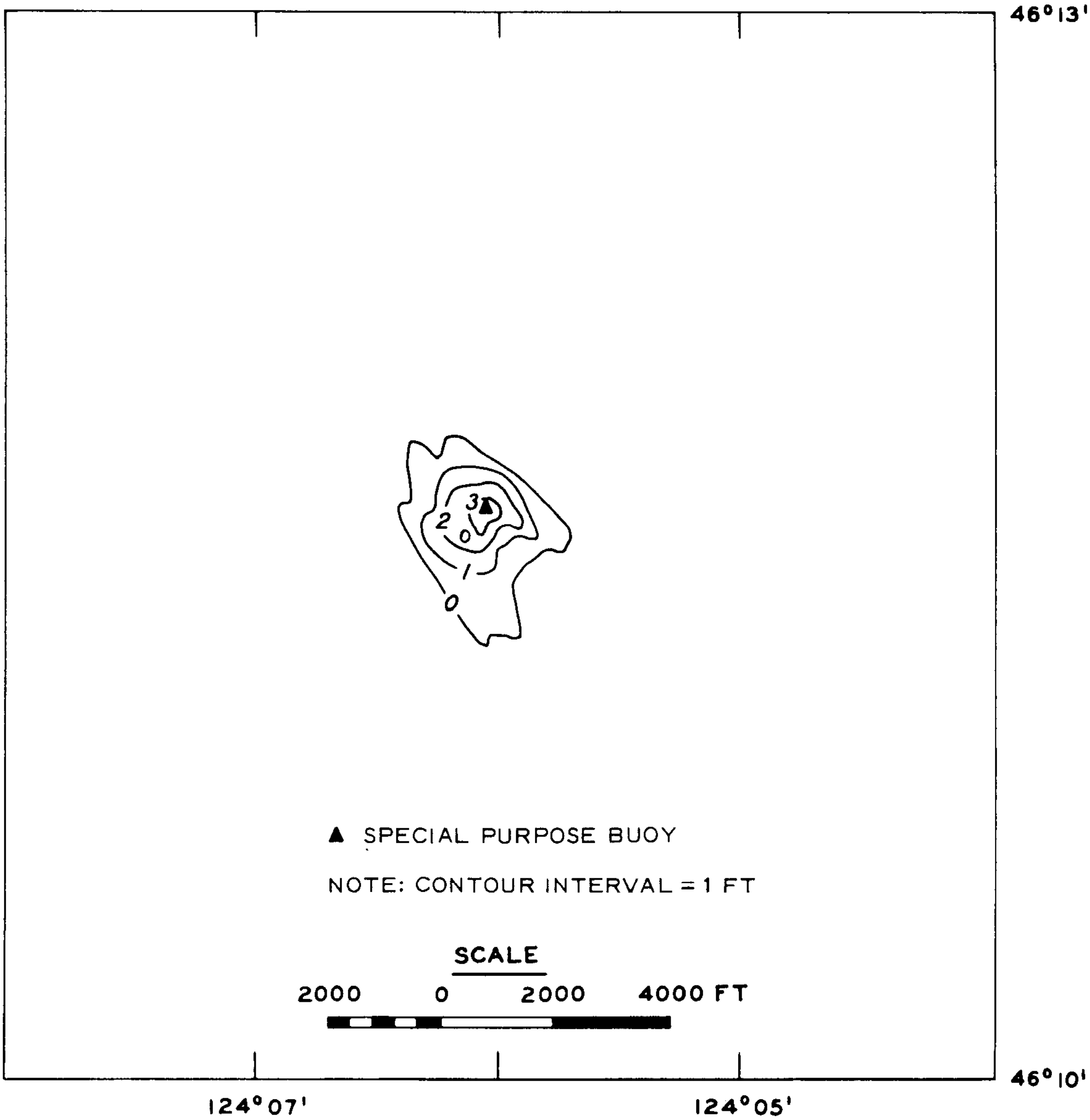

Figure 18. Bathymetry change at area G as of 2 February 1976

exist in the volume calculations, bathymetric surveying, and estimation of the amount of dredged material released by the hopper dredge. This estimate was based on comparisons of pre- and postdisposal bathymetric changes. Subsequent determinations, which involved longer time periods, utilized comparisons of regional bathymetry by extension of the contours through the experimental disposal area to measure volumetric changes there. The volume of the disposal mound, as calculated from the later surveys in January and February, decreased in size to approximately 191,000 m^3, a decrease in size of about 41 percent. Evaluation of these later surveys suggests that the disposal mound was migrating to the northwest along the normal bottom contours and that the surface irregularities observed in the September survey were becoming less pronounced.

85. Tidal currents and near-bottom circulation. Instrumented tripods were deployed at disposal area G during the periods 19 August to 12 September 1975 and 12 December 1975 to 6 January 1976. The instrument used in the latter deployment was not recovered. The maximum tidal range observed during the summer sampling period was 3.1 m. Between 27 August and 2 September, a major oscillation in mean sea level occurred as the mean sea level was depressed approximately 0.8 m. This oscillation was observed at both tripod stations (4 and 5) and was correlated with a major storm which occurred in the area on 26-31 August.

86. Bottom current speeds, in general, were less than 20 cm/sec during this deployment. Analysis of the U (east-west) and V (north-south) components of the bottom flow suggests that semidiurnal tides were predominant during this deployment period. Bottom current speeds during the interval of major sea level fluctuations increased to about 42 cm/sec, approximately twice the normal tidal component for the area.

87. Net bottom flows, as shown in a progressive vector diagram (Appendix A, Figure A66) for tripod station 4 (disposal area G) showed a consistent trend toward 321°T at approximately 6.5 cm/sec. Net flows at station 5 (disposal area G control station), however, were more complex (Appendix A, Figure A67). During the first few days of the record, the bottom flows were toward the southeast. As the major storm passed, bottom currents fluctuated, with distinct periods of southeasterly and

northerly flows which generally corresponded to fluctuations in winds. The net flow speed over the entire sampling period for this station was 1.1 cm/sec at 300°T. Figure 19 summarizes the relationship between surface winds and net nontidal flows for the deployment period 19 August to 12 September 1975 for tripod stations 4 and 5.

88. Bottom turbidity. Transmissometer records for tripod stations 4 and 5 show that suspended sediment concentrations were relatively low (less than 2 mg/ℓ) throughout most of the sampling period. Between 23 and 27 August, the suspended sediment concentration increased to a level of 4 to 10 mg/ℓ. Numerous short-period fluctuations (up to 100 mg/ℓ)

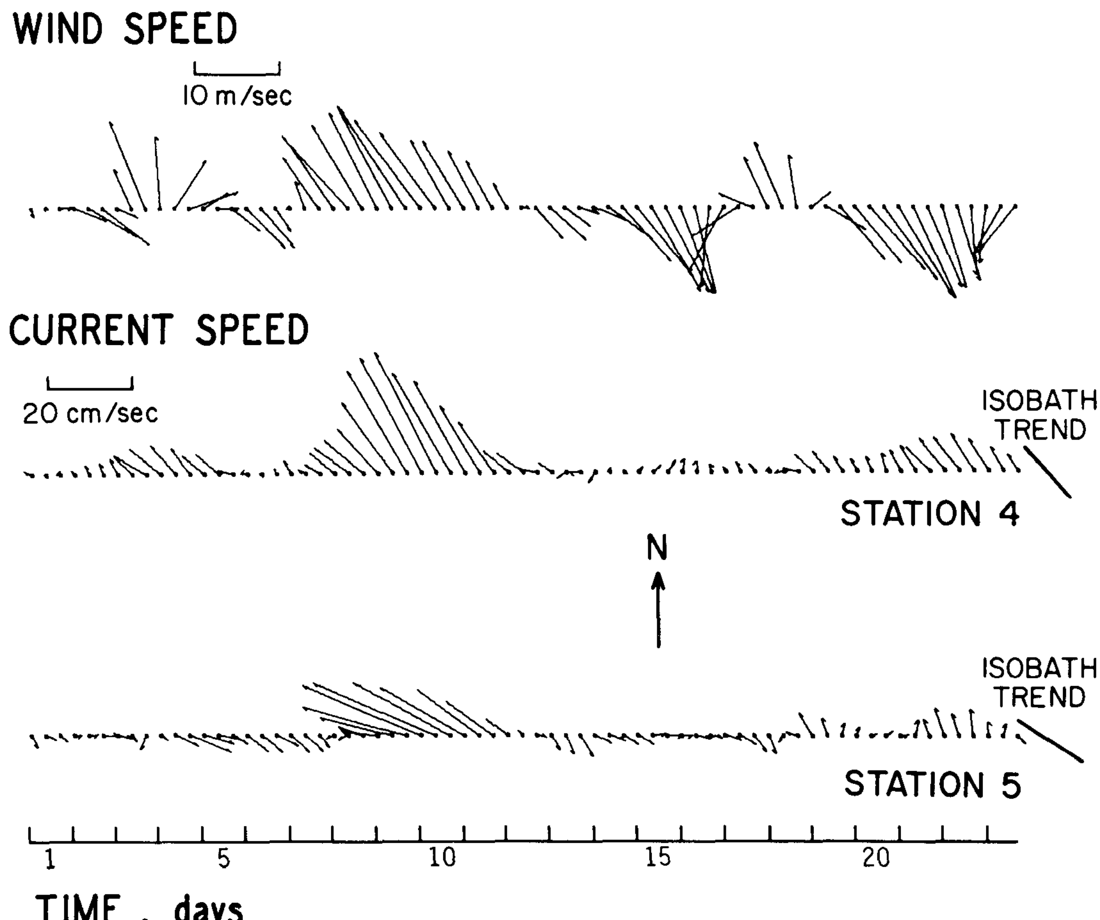

Figure 19. Columbia River winds and net nontidal component of current speed recorded at stations 4 and 5 at disposal area G during the period 1300 19 August 1975 to 0800 12 September 1975. All data were averaged over 25-hour periods and plotted as the direction toward which the flow was moving

were observed along with this general increase at station 4. These short-period fluctuations, however, could not be correlated with hopper dredge records of disposal at disposal area G. On the contrary, the first 5 days of the record at station 4 were characterized by very low suspended sediment concentrations even though a daily average of 5700 m^3 of dredged material was released there.

89. Sediment texture. Sediments at disposal area G prior to disposal consisted primarily of fine to very fine sand having dominant modes of 2.75 and 3.25 ϕ (factors 3 and 4). Small amounts of factor 2 sediment (2.5-ϕ mode) occurred in the vicinity of disposal area G; however, no factor 1 sediment (2.0-ϕ mode) occurred in the area. Immediately following disposal, coarser sediment (factor 1) was found near the special purpose buoy, concentrated along an arc south of the buoy which represents the general path of the hopper dredge as disposal occurred. The largest concentration of factor 2 sediment occurred as a "halo" around the factor 1 sediment. This grain-size sorting may have been due to the diffusive currents associated with the impact of sediments on the bottom. Factor 3 sediments were found as a narrow "halo" around factor 2 sediments; the finest fraction, factor 4 sediments, occurred only in the southeast corner of the sampled area.

90. In subsequent months following disposal, the general trends observed were that the areal extent of the coarser sediments (factors 1 and 2) was reduced as the finer fractions occurred over larger areas within the confines of the disposal area. The density of sampling following disposal was not as great as before; however, 12 stations within the disposal area were resampled for periods of up to 8 months following disposal. Temporal changes in sediment size and factor loadings were found at these stations. Examination of these temporal trends suggests that factor 3 sediment was gradually covering the dredged material mound from all sides, in no directional pattern. Factor 2 sediment, which was present at the area before disposal, probably represents the coarsest mobile sediment in the region and as a result was not covered as quickly as factor 1 sediment which was static on the bottom. The overall rate of return of factor 4 sediment (3.25-ϕ mode) was slower

than that of factor 3 sediment due to its tendency to be transported from the south in suspension rather than as bed load as was probably the case for factor 3 sediment.

91. Sediment mineralogy. Prior to the experimental disposal at area G, MR values were generally less than 2. Two predisposal surveys suggested that no seasonal change in sediment distribution could be recognized and that the mineralogy of area G provided a great contrast with Columbia River sediment. At the conclusion of the disposal operation, MR values ranged from 4 to 5, with values as high as 6 south and east of the special purpose buoy. These high values are related to dredged material originating in the Columbia River.

92. Three months after the conclusion of disposal at area G, the high MR values of 5 and 6 had smoothed out, and the samples near the outer edges of the disposal area had MR values similar to those before disposal. This temporal trend of decreasing MR values continued through June 1976 as predisposal conditions returned. Apparently, the edges at the disposal area are gradually being covered by natural sediments, thereby reducing the MR values to ambient shelf levels.

Sediment transport

93. The determination of sediment movement induced by tidal and wave currents near the bottom in an area such as the mouth of the Columbia River is a difficult task. Nevertheless, estimates of the rate, direction, and dominant sediment transport mechanism have been made. These estimates were based on a combination of generally accepted competency curves (see Appendix A, Figure A131) used to predict the threshold conditions for grain movement, an analysis of the bottom currents measured by the instrumented tripods, and the textural composition of the bottom sediments in the study area. Table 5 lists the percent of time that threshold conditions for grain movement for various size classes were exceeded. It can be seen that bottom currents sufficient to induce grain movement did not occur during some summer months, but occurred as frequently as 20 days/month (66 percent) during the December-January period. In general, however, the frequency of grain movement on a seasonal basis was directly related to elevated bottom currents

Table 5

Required Bottom Currents for Bed-Load and Suspended-Load Transport and the Percent of Time These Speeds Were Exceeded at Tripod Stations

Sediment Characterization			Current Speed Required for Transport, cm/sec		Percent of Time Current Speed Required for Transport Was Exceeded											
					Apr-May 1975				Jun-Jul 1975		Aug-Sep 1975				Dec 1975-Jan 1976	
					Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Modal Size		Factor		Suspended	Bed	Suspended	Bed	Suspended	Bed	Suspended	Bed	Suspended	Bed	Suspended	Bed	Suspended
ϕ units	mm	No.	Bed Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load
2.00 to 2.25	0.25 to 0.21	1	30 to 29	156 to 118	8	0	11	0	0	0	3	0	3	0	66	0
2.50	0.18	2	29	90	8	0	11	0	0	0	3	0	3	0	66	0
2.75	0.15	3	29	65	8	0.2	11	0.1	0	0	3	0	3	0	66	4
3.25	0.11	4	29	34	8	5	11	6	0	0	3	2	3	2	66	43
3.75	0.071	5	29	29	8	8	11	11	0	0	3	3	3	3	66	66
4.50	0.044	6	29	29	8	8	11	11	0	0	3	3	3	3	66	66
6.00	0.016	7	29	29	8	8	11	11	0	0	3	3	3	3	66	66

associated with the passage of severe storms.

94. There are two principal means by which sediments may be transported. These are bed-load transport and suspended-load transport. The mode by which particles may be transported is dependent upon the flow regime and the nature of the sedimentary particle. The results of this study suggest that the coarser sediments in the study area are not transported by suspended load but rather by bed load. The coarsest-grained sediments, 2.5-ϕ and coarser (coarser fractions of factors 1 and 2), were not suspended during episodes of the strongest currents. The size limit for full suspension appeared to be 2.75 ϕ, associated with factor 3, for which sediment was occasionally suspended during the winter and spring periods. Finer sediments were generally carried in suspension once threshold conditions were surpassed, and as a result the percentages listed in Table 5 for suspended load are generally identical with those cited for bed load.

95. Bed-load transport. Data collected during storm periods in 1975 (maximum current velocities of 80.1 cm/sec) were used to estimate the bed-load mass transport of sand. These estimates were based on a procedure described by Sternberg.[17] The storm episodes analyzed represented different levels of intensity, and as a result only approximations of the distances and quantities of sand movement were obtained. Table 6 lists the results of these computations.

96. Bed-load transport values shown in Table 6 were calculated in terms of mass sediment transported per unit width of the bed per second (grams per centimetre per second). These values were summed over the duration of each storm and tabulated as grams per centimetre per storm and multiplied by the east-west width of the experimental disposal area (518 m) to determine the mass of sand transported northward across the total deposit per storm. In addition, the mass transport was converted to volume transport using the following relationship:

$$Q\rho_s \, (0.6) = j^1 \qquad (1)$$

Table 6

Estimates of Mass Transport of Bed Load and Travel Distance of Sand During Severe Storms of 1975

	Station 4	Station 5	Station 6	Station 6*
Dates	26-30 Aug	26-30 Aug	21-24 Dec	24-26 Dec
Mean wind speed, m/sec	13.5	13.5	14.8	10.0
Sediment modal size, ϕ units	2.75	2.75	2.50	2.50
Bed-Load transport				
g/cm/storm	9.2	7.7	68.0	4.3×10^3
g/deposit/storm	4.8×10^5	2.5×10^5	3.5×10^6	2.2×10^8
cm^3/deposit/storm	3.0×10^5	2.5×10^5	2.2×10^6	14.0×10^6
yd^3/deposit/storm	0.4	0.3	2.9	183
Transport distance, m/storm	2.1	1.8	11.0	53

* These values represent about 55 percent of the total, since data collection was interrupted midway through the passage of the storm.

where

Q = volume transport, cm^3/deposit/storm

ρ_s = sediment density

0.6 = factor for converting sediment density to bulk density

j^1 = the mass transport, g/deposit/storm

When these results are applied to the experimental disposal area, it can be approximated that a particular storm may transport as bed load on the order of 0.3252 m^3 of medium to fine sand (factors 1 and 2) for distances ranging from 2 to 100 m. Computations were also conducted which suggested that, on an annual basis, approximately 635 m^3 of sediment was transported northward as bed load from the experimental disposal area during 1975. The travel distance for this material was approximately 440 m for the year. These calculation, however, do not represent the net annual quantity of sand transported away from the area since, on an annual basis, some similar type of sediment from other areas may be transported to and deposited in the area.

97. Suspended-load transport. Measurable quantities of suspended sediments were found in the study area during all seasons sampled. It has been well documented that the Columbia River is the most basic source of suspended sediment in the study area. These sediments have been observed near the river entrance as both irregular fluctuations related to turbulent eddy motions in bottom flow and migration or shifts of the salt wedge intrusion. A second process whereby suspended sediments are introduced to the study area is through the resuspension of bottom sediments by bottom currents including wave surge. As mentioned above, the finer sediments in the study area (factors 5, 6, and 7) move primarily as suspended load. Threshold conditions for these materials were exceeded 66 percent of the time during the winter months. Bottom oscillatory currents produced by surface waves represent another means whereby bottom sediments are placed into suspension. Data collected during this study during various seasons show a high degree of variation of bottom sediment suspension by waves. It was determined that threshold conditions which caused bed deformation (wave-generated ripples) required a minimum pressure fluctuation ΔP of 0.10 kPa (0.7 psi). The

following tabulation summarizes the percent of time when threshold conditions for sediment suspension were exceeded for various seasons:

Station	Dates	Percent of Time ΔP Exceeded
1, 2	Apr-May 1975	21
3	Jun-Jul 1975	21
4, 5	Aug-Sep 1975	6
6	Dec 1975-Jan 1976	9

98. It is obvious that wave activity in the study area, including the experimental disposal area will frequently initiate sediment movement. The coarser sediments characteristic of the experimental area, however, are not carried far from the sea floor by oscillatory wave-generated currents and tend to rapidly settle back to the bed. The net result of the combined effects of wave activity and other bottom currents will be that the dredged material deposit will gradually become smoothed out and spread towards the north-northwest. It is expected that this sedimentary feature will be relatively stable and bathymetrically recognizable for a few years.

Chemical Studies

99. Water column and sediment chemical properties were measured in the study area on cruises before, during, and following disposal. Chemical cruises were completed during September 1974 and January, June, July, August, and October 1975. The following tabulation summarizes the timing of and properties sampled on each of these cruises:

	Sep 74	Jan 75	Jun 75	Jul 75	Aug 75	Oct 75
Water column nutrients	√	√	√		√	√
Water column nutrients (anchor stations)	√		√	√	√	√
Sediment	√	√	√		√	√
Water column metals			√	√	√	√

A more detailed description of the sampling and analytical methods used during these studies may be found in Appendix B to this report. The specific locations of each of the stations sampled for chemical properties are shown in Figures B1-B9, Appendix B.

Predisposal water column nutrients

100. Samples were collected from seven stations during September 1974. These stations were located both in disposal area B and south of the river mouth. While all stations were not sampled over complete tidal cycles, they do provide some information on the water column nutrient chemistry in the study area for these seasons.

101. During September, average nitrate + nitrite values from all stations typically ranged from about 130 μg/ℓ at the surface to approximately 278 μg/ℓ near the bottom. Surface values were highly variable due to tidal effects and the discharge of the Columbia River.

102. Dissolved oxygen values measured in the water column during September were generally higher at the surface (averaging about 7.3 mg/ℓ) than near the bottom where they averaged 4.4 mg/ℓ, with the lowest value being 2.5 mg/ℓ in the vicinity of disposal area A. Higher surface values were probably related to atmospheric exchange and biological activities, while depressed oxygen values in the bottom waters appeared to be related to ebb tidal period. No systematic spatial differences in the dissolved oxygen values could be found in the September data.

103. Particulate carbon and nitrogen values measured during September displayed trends similar to other nutrient data. Average surface values of particulate carbon and nitrogen were 375 and 49 μg/ℓ, respectively. Bottom concentrations of these properties averaged 306 and 25 μg/ℓ, respectively, across the September 1974 stations. However, both surface and bottom values of particulate carbon and nitrogen were highly variable within this time period, and the measured values were less than those observed during June 1975, as will be shown later. This variation undoubtedly was due to tidal oscillations.

104. Surface chlorophyll a values, which can be used as a measure of phytoplankton biomass, were generally low during September 1974 (average value of 3.1 μg/ℓ). Highest surface chlorophyll a values during this month (4.94 μg/ℓ) were found in the vicinity of the experimental disposal area near midday.

105. The biological "health" of water column samples collected during September was estimated by determining the carbon/nitrogen ratios at various depths. It is generally agreed that the carbon/nitrogen ratio of water samples containing healthy cells will range between 5 and 8, while ratios above 8 suggest either dead cells or a high contribution of carbon-rich detritus in the sample. Average surface carbon/nitrogen ratios for September samples were 8, indicating only marginally healthy phytoplankton cells. Bottom carbon/nitrogen ratios were generally higher and more variable (averaging 13.1 with a maximum of 27). These ratios are difficult to interpret since the measurements were not made with sufficient regularity to delineate tidal and diel effects.

106. Water column samples were taken from eight stations in the study area during January. These samples were not analyzed for a complete nutrient series, and no anchor series was taken. As a result, no further discussion of these water column samples is warranted.

107. Two anchor stations were sampled in mid-June 1975, one in disposal area B and the second over the experimental disposal area. At anchor station 1, surface water nutrients reflected tidal heights (flood slack). The lowest values for NO_3, total N, PO_4, and total P in surface waters were coincident with flood slack periods, suggesting that surface ocean water in this area was relatively low in nutrients. During ebb slack periods, the nutrient concentrations at this station were very high and relatively uniform throughout the water column. Surface water entering the vicinity of this station from the Columbia River Estuary during ebb was very low in all nutrients (with the exception of SiO_4); however, deep, nutrient-rich water was entrained to the surface during ebb flow periods, resulting in the observed distribution patterns. No strong tidal effects were observed in the nutrient data at anchor station 2 during June. Other biological patterns emerge from the data. The most obvious feature at this station was a pocket of low-nutrient surface water between midday and midnight on 18 June 1975 which was related to the radiation cycle and biological uptake. When plots of pH, dissolved oxygen, chlorophyll a, and particulate carbon are examined in conjunction with the other nutrient data, it can be seen that

the low-nutrient surface waters were a biological phenomenon rather than a tidal one.

Predisposal sediment nutrients

108. Oil and grease. Low levels of oil and grease (less than 100 mg/kg) were generally found in sediment samples recovered during the study. Occasionally, concentrations greater than 700 mg/kg were found in the vicinity of disposal area B. These elevated concentrations are thought to have been caused by the abundance of fine-grained materials near this area. With the exception of those samples taken near disposal area B, there was little change in the concentration of oil and grease with depth in the sediment cores. There appeared to be a slight reduction in the concentrations in the sediments between September 1974 and January 1975 which may have been due to either winnowing of fine-grained materials out of the area or burial by cleaner, coarser materials as a result of winter storm activity and associated bottom currents.

109. Ammonia. No ammonia measurements in the sediments were made during September 1974 and January 1975. During June 1975, five box cores were taken in the entrance channel to characterize the sediment chemistry of the dredged material. Ammonia values measured in these cores were very low (less than 2 mg/kg) and showed little variation with depth in the core.

110. Particulate carbon and nitrogen. Values of particulate carbon and nitrogen displayed the same trends as those described above for oil and grease during September 1974 and January 1975. In the vicinity of disposal area B, particulate carbon and nitrogen values during September were as high as 12,500 and 1,000 mg/kg, respectively. These values both decreased to near background levels (200 and 100 mg/kg) with depth in the sediment core. The elevated levels described above were due to the presence of fine-grained, highly productive sediments in an area of both natural and man-influenced deposition. During January, particulate carbon and nitrogen values were at or near background levels. Exceptions to this trend were observed at one station in disposal area B where surface levels of particulate carbon and nitrogen were near

background levels, while levels at depth (25 cm) in the cores were significantly elevated. This phenomenon can probably be explained in terms of burial of the finer-grained sediments by coarser-grained sediments as mentioned earlier. Samples taken at the dredging site during June 1975 reflected very low levels of particulate carbon and nitrogen. The sediments recovered from the entrance channel consisted of clean, medium- to fine-grained sand which contained very little organic matter.

111. pH and Eh. The pH and Eh values obtained from sediment samples during the entire study demonstrated some variability; however, no obvious spatial or temporal trends could be established in the data. The values for each property were within normal ranges (7.5 to 7.8), and, as a result, further discussion of these measurements would not be pertinent.

112. Cation exchange capacity and sulfide. The measured values of these properties before disposal displayed trends similar to those described above. With the exception of data for sample stations near disposal area B, all values for cation exchange capacity and sulfide were within an expected range for sandy sediments. Sediments in the entrance channel dredging site showed cation exchange capacity and sulfide values of 2.00 meq/100g and 5 mg/kg, respectively.

Predisposal sediment metals

113. Similar distribution patterns were observed in the total sediment metal data. Background levels of the suite of metals studied were found in the fine to medium sand samples taken from sites south of the river mouth. Occasionally, elevated levels of several of the metals were observed in the vicinity of disposal area B. These levels, however, were not indicative of polluted materials but are within the ranges of those found in clean sand. Spatial, temporal, and within-core variations were not observed in the sediment metal data throughout the study period. Also, there were no obvious differences in the pre- and post-disposal metal chemistries of the sediments at the experimental disposal area. Figures B107-B126, Appendix B, depict the seasonal distribution patterns of the various metal species. For reasons discussed above, further discussion of each metal species would provide little useful

information. Table 7 provides a summary of the sediment metal data collected throughout the study.

Water column metals during disposal

114. Water column samples were recovered at the experimental disposal area for metal analysis during July 1975. The data collected on water column metals before, during, and immediately following disposal are summarized in a series of graphs (Figures B127-B141, Appendix B). General trends in the dissolved and particulate metal distributions are discussed below.

115. Nickel. Both dissolved and particulate concentrations of nickel before and during disposal were generally less than 0.5 μg/ℓ, and the levels were nearly uniform at all depths. Dissolved nickel levels at the experimental disposal area in the upper water column (above 15 m) before disposal were slightly higher than those during disposal. These higher values (1.5 μg/ℓ) probably relect input of nickel from the Columbia River. Nickel values below 15 m were less variable and approached predisposal concentrations.

116. Iron. Particulate iron values in the surface waters during disposal were highly variable, ranging from about 55 to 130 μg/ℓ. These values decreased slightly at middepths; however, they increased to about 80 μg/ℓ near the bottom. Releases of particulate iron to the water column can probably be explained in terms of the iron cycle in natural waters whereby reduced iron is oxidized by the dredging and disposal process and precipitated along with other suspended particulates. This process has been documented by Windom[18] in the southeastern U. S.

117. Manganese. Dissolved and particulate manganese values displayed patterns similar to those of iron. Surface values, however, were quite high (75 μg/ℓ) and also highly variable. River waters, according to Goldberg et al.,[19] show average manganese values of 7 μg/ℓ. Cutshall and Johnson[20] found soluble manganese values to range from 2 to 28 μg/ℓ and particulate manganese values to range from 16 to 69 μg/ℓ in a freshwater section of the Columbia River. Lee et al.[21] found substantial releases of manganese in elutriate testing both under oxidizing and reducing conditions. Chen et al.[22] found measurable releases of iron

Table 7

Means ($\overline{X}$) and Standard Deviations (SD) of Concentrations of Metals in Sediments Collected in the Study Area

		Concentration of Metal in Sediment, mg/kg									
	Depth of	Sep 1974 (N=9)		Jan 1975 (N=8)		Jun 1975 (N=5)		Aug 1975 (N=5)		Oct 1975 (N=5)	
Metal	Core, cm	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Cadimum	0 to 5	0.36	0.33	0.12	0.073	0.06	0.022	0.064	0.069	0.048	0.033
	10 to 15	0.13	0.10	0.21	0.204	0.05	0	0.042	0.033	0.041	0.035
	15 to 20	0.16	0.10	0.11	0.063	0.05	0	0.047	0.046	0.020*	--
Copper	0 to 5	4.5	4.0	1.67	0.23	0.78	0.59	3.8	3.1	2.5	0.43
	10 to 15	4.3	6.1	1.91	0.48	0.68	0.24	2.2	0.13	2.5	2.9
	15 to 20	4.5	7.2	2.15	0.91	0.88	0.72	2.2	0.06	2.1*	--
Iron	0 to 5	5156	1894	3900	363	3560	351	4093	1057	3670	259
	10 to 15	4700	1826	4100	529	3620	444	3640	82.2	3780	249
	15 to 20	4938	2820	4375	987	4267	520	3667	230.9	4000*	--
Manganese	0 to 5	291.7	638.4	44.7	5.1	46.6	15.8	59	20.3	53	10.5
	10 to 15	68.6	44.5	46.3	11.8	42.6	10.6	46	9.5	46	6.2
	15 to 20	76.3	82.2	51.9	19.2	44.0	7.5	39.7	3.2	41*	--
Nickel	0 to 5	4.9	1.7	4.3	0.41	4.7	1.2	4.3	0.63	4.3	2.9
	10 to 15	4.6	2.1	4.6	0.77	5.7	1.2	4.2	0.71	4.2	0.65
	15 to 20	4.9	3.3	4.7	0.98	6.2	1.3	3.5	0.66	44*	--
Zinc	0 to 5	33.3	25.9	14.4	2.2	9.1	2.5	12	3.9	10.8	7.2
	10 to 15	30.9	36.5	15.5	4.3	9.7	3.3	8	1.6	8.7	1.7
	15 to 20	16.8	11.3	14.7	5.9	9.7	2.7	8.4	0.81	9.4*	--
Lead	0 to 5	5.7	3.3	3.5	1.2	2.0	0.32	15.2	28.2	2.9	0.99
	10 to 15	5.7	5.8	3.2	1.2	1.7	0.46	2.5	0.60	2.4	1.1
	15 to 20	4.1	2.4	3.9	1.7	2.1	0.36	2.1	1.19	2.4*	--
Mercury	0 to 5	0.712	1.98	0.38	1.06	0.0078	0.0019	0.020	0.017	0.015	0.023
	10 to 15	0.469	1.32	1.13	3.18	0.0087	0.0014	0.012	0.011	0.008	0.002
	15 to 20	0.018	0.021	1.51	3.67	0.0128	0.0072	0.008	0.002	0.006*	--

* This value was determined for one less sample than indicated.

and nickel, as well as manganese, in Los Angeles Harbor sediments.

118. Copper. Water column dissolved and particulate copper levels before and during disposal fluctuated randomly between 0.1 and 0.55 μg/ℓ. No obvious trends were displayed by the data, and the concentrations measured were similar to those expected in seawater, according to Brewer.[23]

119. Zinc. Before and during disposal, particulate and dissolved zinc values fluctuated randomly throughout the water column. The maximum dissolved value (1.8 μg/ℓ) was observed at 15 m, while the highest particulate value (2.5 μg/ℓ) was found at the surface. Buffo[24] found that Northeast Pacific Ocean surface waters averaged 22 μg/ℓ, with concentrations decreasing with depth. It is possible that some of the erratic fluctuations observed in the zinc levels were due to biological concentration by marine plants and animals. There was, however, no evidence that any of the high zinc values were related to disposal activities.

120. Cadmium. Knauer and Martin[25] have reported cadmium values in Pacific nearshore seawater ranging from 0.03 to 0.15 μg/ℓ. Before and during disposal at the study area, dissolved cadmium values exceeded particulate values in all cases, with the maximum value of 0.1 μg/ℓ before disposal occurring at 15 m. All cadmium values demonstrated random variability throughout the water column; however, no obvious correlations with disposal activities could be found, and the measured values were not considered to be indicative of pollution.

121. Lead. Measured water column values of lead showed higher levels of particulate lead at the surface (0.225 μg/ℓ) before disposal. These values decreased to about 0.025 μg/ℓ at 15 m both before and during disposal. Renfro et al.[4] suggest that typical seawater values of lead are 0.1 μg/ℓ but that values as high as 1.5 μg/ℓ may be found in locally polluted areas. Values found during this study were generally less than 0.15 μg/ℓ, suggesting that the disposal effects could not be seen in the lead data.

Postdisposal water column nutrients

122. Nitrate + nitrite. Nutrient data, as well as hydrographic data, during late August for the experimental disposal area showed tidal effects. The highest nutrient values in surface waters fit well with maximum ebb velocities, and the lowest surface nutrient values correlated well with maximum flood velocities. Oceanic water with a high nutrient gradient (low at surface, high near bottom) oscillated across the experimental disposal area in phase with flood tides, while the ebb tide brought higher surface nutrients by entraining deeper oceanic water into surface layers.

123. During October 1975, water column nutrients both at the experimental disposal area and at area B showed bottom and surface values higher than those at intermediate depths. These nutrient distributions apparently were maintained by salinity gradients during this transition season. Nitrate + nitrite at the surface over the experimental disposal area showed two occurrences of high concentrations (50 μg/ℓ) which were in reasonable agreement with high ebb velocities.

124. pH. The pH data for the experimental disposal area in late August 1975 displayed trends similar to those of other nutrient data. However, the lowest pH values (8.0) at the surface were associated with maximum flood velocities. The movement of higher pH oceanic surface water across the disposal area at this time was related to the higher biological productivity (and/or lower biological decomposition) in the surface ocean waters when compared with both river-influenced surface water and deeper waters that were being entrained to the surface during periods of maximum ebb. During October, uniform pH values were observed at both anchor stations, reflecting the transition period between summer and winter conditions. Slightly higher pH values were found at intermediate depths which were probably related to nutrient minima at these depths.

125. Dissolved oxygen. Measurements of dissolved oxygen in the water column following disposal demonstrated trends very much similar to those for the nutrient and pH data. During October 1975, uniform distributions of high oxygen values were found at both sampling stations.

Oxygen values as high as 7 mg/ℓ were measured near the bottom during this transition period. Tidal effects were also less clear at this time.

126. Chlorophyll a and particulate carbon. The chlorophyll *a* and particulate carbon data measured during August also suggest very strong associations with the nutrient, oxygen, and pH data. It was clearly evident that very high primary production was associated with the movement of oceanic water over the station. These observations may also be explained in terms of upwelling of deeper, more productive bottom waters during this time period. A major sea level fluctuation was documented between 27 August and 2 September 1975. During this period, the mean sea level was depressed 0.8 m following the atmospheric disturbance. Bottom currents measured by instrumented tripods during this period (up to 42 cm/sec) were about twice the normal tidal current component and the direction of flow was north and offshore between 300 and 330°T.

127. Biomass data for October 1975 reflected the uniform distributions of chlorophyll *a* and particulate carbon in the water column at both stations. These distributions were similar to those observed in the other nutrient data.

Postdisposal sediment nutrients

128. Oil and grease. Oil and grease determinations at the experimental disposal area immediately following disposal averaged about 60 mg/kg, which represents concentrations less than or equal to those taken from the area prior to disposal. Two months after disposal, oil and grease values in the vicinity of the experimental disposal area still averaged 60 mg/kg. One sample recovered from near disposal area B showed elevated levels of oil and grease as well as other nutrients and metals.

129. Ammonia. Measurements of ammonia following disposal showed no indication of unusually high concentrations. With the exception of one sample mentioned above, ammonia values following disposal were all less than 2 mg/kg, indicative of clean sand dredged from the Columbia River.

130. Particulate carbon and nitrogen. The particulate carbon and nitrogen values from samples recovered at the experimental disposal area often were very low (200 and 100 mg/kg, respectively). There was very

little variation with depth in the sample observed in the data for these properties. Pre- and postdisposal concentrations of particulate carbon and nitrogen were nearly identical.

131. pH and Eh. Values of these sediment properties displayed some random variability following disposal; however, similar variabilities were noted prior to disposal. All of the values measured were considered to be within normal ranges for clean sandy sediments.

132. Cation exchange capacity and sulfide. As with other sediment properties, values of cation exchange capacity and sulfide following disposal were identical with predisposal levels. One sample collected in the vicinity of disposal area B showed elevated levels of these properties which would be expected based on previous findings.

Postdisposal sediment metals

133. Sediment metal data following disposal suggest that the disposal operation had no discernible adverse effect on the sediment metal chemistry at the experimental disposal area. In many cases, it was apparent that the release of dredged material at the disposal area had the effect of stabilizing the heavy metal variation within the sediments following disposal. The only metals which displayed trends contrary to the above were lead and mercury; a slight increase for each of these properties was noted. It is very difficult to explain this trend since the dredged material itself was found to contain mercury and lead values of 8 μg/kg and 2 mg/kg, respectively, before dredging. Following disposal, mercury and lead values as high as 50 μg/kg and 4 mg/kg were found at the disposal area. Regardless of this anomaly, mercury and lead values measured were not indicative of pollution.

Postdisposal water column metals

134. All of the metals studied in the water column, both in dissolved and particulate form, fluctuated within expected ranges following disposal. It was apparent from the data that the disposal operation had no measurable effect on the metal chemistry of the water column above the experimental disposal area. The majority of the fluctuations observed in these data can be attributed to soluble and particulate metal input from the Columbia River, biological activity and processes, and

analytical problems associated with determinations near detection limits.

Benthic Studies

135. These studies include results from 1,359 0.1-m^2 Smith-McIntyre grabs for macrofauna (greater than 1.00 mm) and 67 metered beam trawls for megafauna. A total of 339,753 individuals (425 species) were sorted and identified from the Smith-McIntyre grab samples, and 258,501 individuals (141 species) were sorted and identified from the beam trawl samples.

136. The locations of stations for the areal baseline were determined from a pilot survey (1-2 October 1974) and from data on the distribution of sediments provided by the physical contractor at the University of Washington.

137. The number of 0.1-m^2 Smith-McIntryre grab samples per station was set at five replicates; however, a rigorous testing of the adequacy of the five replicates was not performed.

138. In addition, the five replicates from each station were pooled, thus preventing any analysis of within-station variation in order to reduce the inherent variation found in benthic studies.

Benthic community structure

139. The distribution of assemblages and species groups and the values of community structure parameters for the study area were determined from samples from an areal baseline of 100 stations collected on 4-9 December 1974 and 19-25 January 1975. From the results of the areal baseline sampling, 22 station locations were chosen to determine seasonal changes in benthic communities. These stations were sampled on 18-23 April 1975, 23-27 June 1975, 11-16 September 1975, and 3-10 January 1976.

140. By the use of classification analyses on Bray-Curtis coefficients calculated for each species or station, five major benthic assemblages and 12 station groups were found off the mouth of the Columbia River during December 1974-January 1976.

141. With the exception of assemblage C (the southern inshore sand assemblage), the species composition, biomass, and density of benthic

assemblages off the mouth of the Columbia River were different or greater than values calculated for other benthic assemblages reported from the Oregon-Washington continental shelf. The influence of the Columbia River (sedimentation patterns and high primary productivity) probably accounts for the difference.

142. The distribution, community structure, and seasonal constancy of benthic assemblages found off the mouth of the Columbia River were interpreted in part to be the result of the same factors that influenced benthic assemblages along the Oregon-Washington coast. These factors included an increase in silt, clay, and organic content in sediments offshore and a decrease in sediment instability due to sediment stirring by winter storms offshore. Superimposed on this depth gradient were the effects of the deposition of fine-grained sediments from the Columbia River and the high primary productivity of the area.

143. Diversity and species richness values were related to sediment stability. In general, the values of diversity and species richness increased offshore probably as the result of the increased sediment stability due to reduced sediment stirring by winter storms. The high abundance of tube-dwelling polychaetes at deeper stations also increased sediment stability. The lowest values of diversity and species richness were calculated for stations that had considerable seasonal changes in sediment texture as a result of the deposition of fine-grained sediments at high flow of the Columbia River.

144. Biomass and density of macrofauna were related to the organic content of sediments. The biomass and density of macrofauna and the amount of organic matter in the sediments generally increased offshore. The highest values of density and biomass were found at areas of high silt deposition because of the high organic content of those sediments.

145. A method of analyzing seasonal variation was attempted that has not been shown to be an adequate test of the hypothesis. Based on arbitrary ranges of values of Bray-Curtis and Czekanowski coefficients for stations across time, there appear to be some trends in the data.

146. The seasonal constancy of species composition may be highest in areas that had the highest seasonal constancy of sediment

characteristics. Benthic assemblages exposed to deposition of fine-grained material by the Columbia River had the highest Czekanowski dissimilarity values (low constancy) between seasons of any stations in the study area. The seasonal constancy of the abundance of dominant species could be related to sediment stability but was not tested. The between-season Bray-Curtis dissimilarity values generally decreased (higher constancy) with increasing sediment stability offshore (reduced stirring of sediments by storms) and were highest at stations that had the lowest seasonal stability, perhaps due to deposition by the Columbia River.

Disposal effects

147. From 9 July 1975 to 26 August 1975, approximately 459,000 m^3 of dredged material was deposited at experimental area G (46°06'N, 124°11.5'W). The experimental area was sampled three times prior to disposal (4-9 December 1974, 18-23 April 1975, and 23-27 June 1975) for a total of 15 stations and five times after disposal (11-16 September 1975, 20-25 October 1975, 3-10 January 1976, 19-20 April 1976, and 7-8 June 1976) for a total of 64 stations. The lack of sufficiently detailed predisposal data taken at the experimental area could severely limit the conclusions of the benthic studies. However, analysis of density estimates for seven stations in the experimental area immediately before disposal (June 1975) shows that, for all species combined, there was no significant difference in density (df(station) = 6; df (error) = 230; $F = 0.21$; $p > 0.97$). Furthermore, analysis of the eight dominant species (based on density) showed no consistent pattern of differences among stations. Therefore, it appears that the seven stations sampled in area G prior to disposal were homogeneous at that time with respect to density. This analysis does not address the amount of seasonal variation that could be expected in area G and is an important source of unaccounted for variation.

148. The station groups calculated from species abundance values were similar to station groups derived from extrinsic parameters that define the extent and magnitude of the dredged material disposal. The extrinsic data included Corps of Engineers records on the disposal operations, observations of predisposal and postdisposal bathymetry, and

textural analysis of predisposal and postdisposal sediments.

149. Because limited predisposal samples were available from area G (15 stations over a 6-month period), postdisposal stations were divided into three groups based on sediment characteristics: (a) affected stations which experienced direct burial and were located on the flat top of the dredged material deposit, (b) intermediate stations which were located on the slope, base, and edge of the depositional area, (c) unaffected stations which were outside the area of deposition.

150. The stations exposed to direct burial of dredged material had significantly higher diversity and evenness values and significantly lower density of macrofauna when compared to unaffected stations. The significant differences in diversity and evenness persisted for at least 8 months after disposal, and the significant difference in density of macrofauna persisted for the duration of the sampling program (10 months after disposal). The following tabulation summarizes these results:

	Relationship of Affected Stations to Intermediate and Unaffected Stations				
	Sep 75*	Oct 75*	Jan 76	Apr 76	Jun 76
Biomass	H	L	S	S	S
Diversity	H	H	S	H	S
Evenness	H	S	S	L	S
Density	L	L	L	L	L

Note: H = affected station had a higher value than either unaffected or intermediate station.
S = no significant difference (at $p \leq 0.05$) among groupings.
L = affected station had a lower value than either unaffected or intermediate station.
* Relationships for this period were determined from Kruskal-Wallis H-tests. All other relationships were determined from Mann-Whitney U-tests.

151. An analysis of the effect of dredged material disposal on 31 dominant species at or near area G showed an almost even split (15 of 31) between those species with a lower density at affected stations and species whose densities were unaffected by dredged material

deposition. Similar results were found for ranked seasonal abundances (16 of 31 significant), but there appeared to be no relationship between seasonal abundance and differences in abundance among stations.

152. The effect of dredged material disposal on benthos was related to their direct burial and slight changes in sediment textural properties and not to increased turbidity from disposal operations or introduction of pollutants or organic matter. This conclusion is based on the facts that turbidity levels at area G during and after disposal were the same as those prior to disposal and, as mentioned earlier, that the sediments at the dredging site and the sediments at area G after disposal contained amounts of several chemical constituents (total sulfide, ammonia, oil and grease, cadmium, copper, iron, lead, manganese, mercury, nickel, and zinc) similar to those in ambient sediments at area G.

Recolonization of disposal site

153. The mechanism of the repopulation of benthos into the affected area is unknown, but it was probably accomplished by benthos burrowing up through the dredged material or migrating into the area or by reproduction and/or recruitment of benthos from outside the affected area. There was very little evidence for transportation of benthos to the experimental disposal area via dredged material. Burrowing is quite common in some benthic species, and the ability to burrow up through 1.5 m of incrementally deposited dredged material in this study may be an important mechanism. Studies by Maurer et al.[26] have shown that some benthos can burrow up through 1 m of dredged material. Migration patterns and maximum immigration distances have not been ascertained for most benthic species. Import into the disposal area is difficult to evaluate since 7 of the 11 species that were dominant in the entrance channel dredging area were also dominant at area G. And finally, spawning appears to be a viable explanation for the drastic increase in density exhibited by Spiophanes bombyx, but cursory data on the density of juveniles at area G show low, evenly distributed densities.

154. In summary, the effect of dredged material deposition at area G off the mouth of the Columbia River on the benthic community is limited to the physical impacts of disposal. If some members of the

community were affected, i.e., tube-dwelling polychaetes and amphipods and species with limited ability to burrow through sediment, the effects were usually short-lived. The dominant influence of one species, *Spiophanes bombyx*, on density and diversity values should not be overlooked or minimized.

Plankton Studies

155. Between January 1975 and October 1975, a total of 340 plankton samples were taken from the vicinity of the mouth of the Columbia River in an attempt to describe the spatial and temporal variations in the community structure of the plankton and to study the effects of open-water disposal on these communities. Zooplankton and ichthyoplankton samples were taken from surface, bottom, and oblique tows at stations which were identical with those described earlier in the discussion of the chemical studies.

156. Both a 1-m and a 0.5-m plankton net were used to collect samples for these studies. The 1-m net (0.571-mm mesh) was towed for 15 minutes at a rate of 3.7 km/hr and filtered approximately 2900 m^3/hr. The 0.5-m net (either 0.233 or 0.110-mm mesh) was also towed at 3.7 km/hr for 7.5 minutes. This net filtered approximately 730 m^3/hr. Surface tows were made by towing the net approximately 1 m below the surface, and bottom tows were generally made at about 3 m above the bottom in calm seas. Oblique tows were made by lowering the net until the weight (113.6 kg attached 2 m below the net) touched bottom, retrieving 1 m of cable, and towing for 1 minute at the depth. At the end of each succeeding minute, 1/15th (1-m net) or 1/7.5th (0.5-m net) of the cable out was retrieved.

Sample identification

157. It was originally an intention of these studies to identify samples to the species level and to the stage of development. Time and staffing constraints however altered this plan. All samples from the January cruise and from stations 1-3 on the March cruise were identified to species and to stage of development. Only samples from 5

selected oblique 1-m net tows from station 2 on the June cruise, 6 oblique 1-m net tows from the same station in August, and 6 oblique tows in October were identified to species level and stage of development. These samples were selected from each of the three cruises on the basis of their equal distribution throughout a 30-hour anchor station at the experimental disposal area (station 2). Each group of samples was spaced 6 hours apart and generally corresponded to a different tidal period.

Summary of catch

158. Ichthyoplankton. All samples collected with the 1-m net were sorted and analyzed for ichthyoplankton. A total of 6320 larval and juvenile fishes from 18 families were taken during the study. Table 8 lists the predominant families of larval and juvenile fishes taken during the studies. Ichthyoplankton abundances were found to be higher during the winter-spring months, with smelt, anchovy, right-eye flounder, codfish, and sculpin accounting for 94 percent of the total ichthyoplankton catch. Larval fish members varied throughout the studies, with no obvious disposal effects. Seasonal trends in larval fish densities could not be quantified due to the level of sampling effort.

159. Zooplankton. The zooplankton catch was dominated by copepods for all seasons sampled. Highest abundances of copepods were observed during January, June, and August 1975. Within the order Copepoda, *Calanus* spp. dominated the copepod numbers, with a seasonal average of 79.7 percent.

160. Among the Mysidacea, *Acanthomysis macropsis* and *Neomysis kadiakensis* were found in nearly identical members on a seasonal basis. The mysids however accounted for only a very small percentage of the total zooplankton catch (usually less than 1 percent). Decapod crustaceans accounted for the only other numerically dominant zooplankton taken during the study, with 18 percent of the total catch during March 1975. As zoea, *Cancer magister* larvae were the most abundant decapod larvae during January 1975 (85 percent); however, as megalopa during June 1975, they represented only 1 percent of the total decapod catch. *Cancer magister* is a commercially important species, and the presence of

Table 8

Composition of Total Ichthyoplankton Catch

Family	Percent Larval and Juveniles
Osmeridae (smelt)	60.6
Engraulidae (anchovy)	12.1
Pleuronectidae (right-eye flounder)	8.9
Gadidae (codfish)	8.0
Cottidae (sculpin)	4.4
Ammodytidae (sandlances)	2.3
Cyclopteridae (snailfish)	1.5
Agonidae (poachers)	1.0
Others	1.2
Total	100.0

its sensitive megalopa stage in the area during disposal operations should be considered.

161. Seasonal trends in the densities of shrimp and crab are shown in Figure 20. It can be seen that, for these groups, peak abundances occurred during the winter months and that by late summer very low numbers were found. The relative percentages of decapods sampled during this study are summarized in the following tabulation:

	Percentage of Major Animals in the Order Decapoda					
	January 1975	March 1975	June 1975	August 1975	October 1975	Average
Cancer magister	85.3	35.4	1.1	0.0	0.0	24.4
Cancer sp.	3.6	2.1	1.6	16.0	1.6	5.0
Pinnotheridae	0.4	0.9	34.2	0.0	40.2	15.1
Other Brachyura	4.4	0.1	6.9	2.3	0.8	2.9
Callinassidae	2.8	4.6	10.0	17.7	10.7	9.2
Paguridae	1.4	8.0	4.4	5.0	14.7	6.7
Porcellanidae	0.9	0.0	0.0	0.3	3.3	0.9
Crangonidae zoea	0.7	43.5	24.8	6.3	3.3	15.7
Crangonidae	0.1	0.0	4.2	0.7	5.7	2.1
Other Natantia	0.5	5.4	13.0	51.7	19.7	18.1

162. Discrimination between tidal and diel activity patterns suggested that each major zooplankton taxon displayed different behavior patterns. Pelagic and planktonic forms did not show any distinct cycle; however, it is believed that this may have been due to sample variability. Zooplankton of benthic origin, however, appeared to exhibit nocturnal activities. This was most clearly demonstrated by the mysid and cumacean data which showed peak densities occurring in bottom and oblique tows during nighttime periods. To a lesser extent, similar distribution patterns were shown by the isopod and polychaeta data.

163. Disposal effects on the zooplankton were not evaluated during these studies due to the contractor's inability to analyze samples taken during disposal. There were several variables which affected the zooplankton catch, none of which could be suitably quantified in order to allow comparisons between catch data. These variables include the inability to predict the activity of a particular animal at a particular time, uncertainties regarding the diel activity patterns of the species

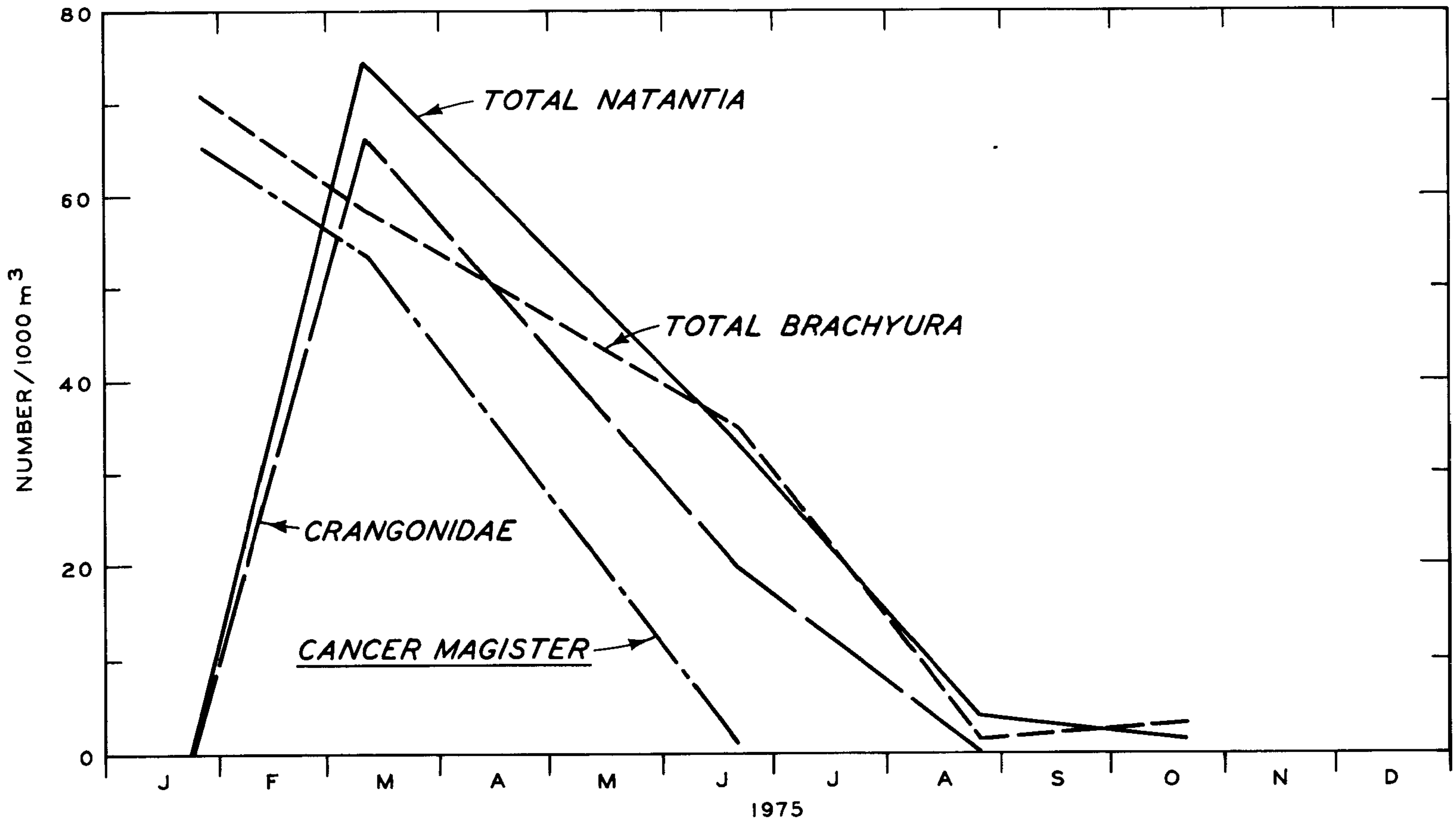

Figure 20. Seasonal abundance of shrimp and crab larvae taken in 1975

of interest, the effects of tides and other coastal currents on the localized distribution patterns of the zooplankton, the variability associated with the fishing ability of the sampling gear, and the mutual nonrandom grouping or patchiness of the zooplankton community. Sullivan and Hancock[27] provide an excellent summary of previous attempts to determine responses of zooplankton to dredging and disposal operations. They conclude by stating that, in many oceanic areas, natural fluctuations in zooplankton populations are so large that field surveys in these areas conducted for the purpose of estimating effects in these populations would probably never be useful. Appendix D should only be used as a broad data base for the Columbia River mouth region.

Demersal Fish and Decapod Shellfish Studies

164. Between October 1974 and April 1976, 151 trawls were made in the study area to describe the composition and spatial and temporal distribution of demersal finfish and decapod shellfish and to study the effects of controlled sediment release by hopper dredges on these indigenous organisms. Demersal fish sampling was conducted at the stations (A-E) shown in Figure 8, with A being the northernmost station. Stations B and C were located in areas that had been used for dredged material disposal during previous years, whereas stations A, D, and E were in areas for which there were no previous records of disposal activity. Station A served as a reference for comparison with station B, and station D served as a reference for station C. Station E was located in experimental disposal area G. Station D was also used as the reference for station E.

165. Sampling was generally conducted on a monthly basis with the exception that no trawls were made at station E until immediately prior to the disposal operation in July 1975, and sampling was not possible at any station during December 1974, February and October 1975, and March 1976. Each trawl lasted exactly 5 minutes and was conducted on a constant compass bearing and at constant engine speed; however, the distance covered by each tow was highly variable. The net used for

trawling was a semiballoon shrimp net. Duplicate trawls were made at each station on each sampling date.

Summary of catch

166. The trawling efforts yielded a total of 86,931 finfish individuals from 51 species and a total of 97,360 decapod shellfish individuals from 13 species. The finfish included 21 species taken rarely (less than 10 individuals), 10 species with less than 100 individuals collected, and 20 species which accounted for the remainder of the finfish catch. The decapod shellfish species collected were dominated by those from the crangonidae and cancridae families. Of the 20 more abundant finfish species, 11 represented nearly 95 percent of the total catch. There was some indication from the catch data that a spatial difference occurred for some of the dominant species. Pricklebreast poacher and showy snailfish were more common at northern stations, while butter sole and Pacific sandab were more common at the southern stations. Whitebait smelt, English sole, and Pacific tomcod were important at all stations, whereas anchovy and longfin smelt were important at all stations except E.

Community structure effects

167. The finfish catch data were used in calculating a number of parameters for the purpose of describing community assemblages at the various stations over time. These parameters were Shannon-Weaver species diversity (H'), species richness (SR), evenness index (J'), catch per unit effort (CPUE), and species per tow. These test indices all showed a large amount of variation over time (generally on a monthly basis), as did the relationship of the parameters among the five stations; however, no significance test was performed to substantiate this variation. These large variations along with the fact that there were insufficient data to estimate the precision for any of the parameters made it difficult and tenuous to compare the trawl catches over time or among stations for one sampling time. However, catch data for station E gave somewhat depressed values for H', SR, CPUE, and species per tow after deposition of the dredged material and for several months thereafter in relation to catch data for the other four stations. There were a number

of possible causes for the high degree of variability in the data, and this should be taken into consideration when interpreting these trends.

Analysis of catch data

168. The analysis of variance of numbers of finfish and shellfish taken at the five sampling stations was limited to the months of July, August, and September 1975 and April 1976. Sampling data gathered between September and April could not be used for comparative analysis because commercial crab gear restricted sampling at several of the stations. Tests of spatial or station differences in catches indicated a significant difference ($\alpha = 0.05$) in 10 of the 11 numerically important finfish species. English sole were the exception, with no differences found in catches between stations. The test of temporal or monthly similarity of catches revealed significant differences in the catches of 9 of the 11 species. Anchovy and showy snailfish were exceptions; however, no consideration was given to the interpretation of the interaction term between stations and time. In addition to the overall significant differences between stations, the analysis also indicated that those differences were not consistent from month to month for each species except anchovy, snailfish, and sand sole.

169. A Q-test was used to compare differences in catches between pairs of stations for the 11 species. In all of the Q-tests, English sole were the only finfish that did not have significant differences in catches between at least two stations. Differences in catches were usually between the northern stations (A and B) and the southern stations (C, D, and E). The northern assemblage of fish consisted of anchovy, whitebait smelt, longfin smelt, Pacific tomcod, pricklebreast poacher, showy snailfish, sand shrimp, and dungeness crab. The southern assemblage consisted of shiner perch, Pacific staghorn sculpin, Pacific sandab, butter sole, and sand sole. The principal species inhabiting the experimental disposal area were sand sole, staghorn sculpin, and butter sole. The consistency of these species and their numbers suggest that they might be considered tolerant of sediment disposal.

Food utilization

170. These studies demonstrated that certain demersal finfish from

the study area showed fairly selective feeding habits. This interpretation of the data takes into consideration several sampling limitations:

- a. Because of natural occurrence or nonoccurrence and sampling inconsistencies, the 11 species of fish were not sampled evenly during all months.
- b. Fish may not have consumed the food items from the area in which they were captured.
- c. Diel and diurnal migrations of both fish and invertebrates as well as unknown daily foraging habits of fish may have affected the results.
- d. Various stages of digestion of the food items limited some of the identifications.

171. Food utilization studies were conducted from January 1975 through April 1976. The sampling procedure was to select a subsample of the numerically dominant species from each tow. This technique had merits but was subjective, resulting in oversampling of some species and undersampling others. The data provided valuable original information regarding the food habits of indigenous species of demersal fish in the study area.

172. Four invertebrate and one fish species were the most extensively consumed prey items off the river mouth. These were the cumacean, *Diastylopsis dawsoni*, the mysid, *Neomysis kadiakensis*, the amphipod, *Atylus tridens*, the shrimp, *Crangon* sp., and the anchovy, *Engraulis mordax*. Food consumption patterns were evident. The anchovy consumed phytoplankton, while smelt ate cumaceans, copepods, and small mysids; an exception were the whitebait smelt, which also consumed small anchovies. Pricklebreast poachers consumed mysids, while the tomcod and showy snailfish ate cumaceans, amphipods, shrimp, and fish. Pacific staghorn sculpin preyed on shrimp and fish. The large-mouth flatfish, Pacific sandab, and sand sole consumed large shrimp and/or anchovy, while the small-mouth butter and English sole preyed on cumaceans, amphipods, shrimp, clams in summer, and a few fish and worms.

173. Specific changes in finfish feeding behavior were difficult to assess at the experimental disposal area since an individual fish could have fed in one area and then swum into the disposal area where it was captured. However, the data suggest that the consumption of

small organisms such as cumaceans, copepods, mysids, and amphipods decreased while consumption of shrimp and fish usually increased during and immediately following disposal. In September and November 1975, feeding behavior of the fish at the experimental disposal area was similar to that of fish caught at the other four stations. Therefore, the burrowing clams and worms utilized during disposal seemed to be replaced by fish and decapod crustaceans as food items. Following disposal, food consumption of those fish taken at the disposal area tended to be similar to that at the other stations.

174. The dredged material released at the experimental disposal area had an apparent effect upon the number of species, number of individuals, size of the fish, and food they consumed. The finfish population appeared to have recovered within several months. Sediment removal from the Columbia River navigation channel annually exceeds 4,000,000 m^3, but deposition at stations B and C in prior years had had no apparent lasting effect on the community structure and number of finfish. The catch data did indicate a larger concentration of individuals at northern stations; therefore, deposition effects would be greatest in that area. Catches at the unimpacted southern station D indicate that finfish numbers were normally low in the summer, and this suggests that there would be less direct impact from deposition at that station.

PART VI: CONCLUSIONS

Physical Studies

Disposal at experimental area G

175. Disposal of approximately 459,000 m^3 of dredged material at the experimental disposal area produced a distinct bathymetric feature generally confined to a radius of 460 m around the special purpose buoy, with accumulation primarily to the south and west of the buoy. Immediately following the disposal experiment, the volume of dredged material at the area was estimated to be 324,000 m^3, representing approximately 71 percent of the material released at the area. It is not suggested that 29 percent of the material released did not make it to the bottom, although undoubtedly some of the silt and clay particles were carried in suspension away from the disposal area. This does suggest that certain inaccuracies exist in the volume calculations, in the bathymetric surveying, and particularly in the estimation of the amount of material actually released by the hopper dredges.

Bottom currents and dredged material dispersion

176. In the vicinity of the experimental disposal area, bottom current speeds during the summer months were generally less than 20 cm/sec, with semidiurnal tidal currents representing the major component of the current structure. Net bottom flows at the disposal area during this period showed a consistent trend toward 321°T at approximately 6.5 cm/sec and roughly along the isobaths.

177. Tidal and wave-generated bottom currents in the study area were found to be capable of initiation of sediment transport, and estimates of the rate and direction, as well as the dominant transport mechanism, were made. Estimates were based on competency curves used to predict threshold conditions for grain movement, on an analysis of near-bottom current structure, and on the textural composition of the bottom sediments. These results suggest that both bed-load and suspended-load transport mechanisms account for grain movement in the

study area. Generally, the coarser sediments were not transported as suspended load but were transported as bed load. The size limit for full suspension appeared to be about 2.75 ϕ (0.15 mm), and particles of this size were only occasionally suspended during winter and spring storm periods. Considering the nature of the sedimentary materials at the disposal area and the nature of bottom currents, it may be concluded that the coarser fraction of the dredged material will remain in place as the finer material becomes winnowed away as suspended material through the combined effects of wave activity and other bottom currents. The net result is that the dredged material deposit will gradually become smoothed out and spread towards the north-northwest, and this feature will be relatively stable and recognizable for a few years.

Chemical Studies

Water column properties

178. Results for those properties measured in the water column in the vicinity of disposal area B suggest that tides and river hydraulics play the dominant role in the observed distributions for nutrient, metals, and biological data. For periods of high river discharge, the nutrient and biological data for this area were primarily influenced by the river, while at other times the combined effects of river discharge and tides accounted for the observed distribution patterns for nutrient and biological data. For the vicinity of the experimental disposal area, however, the nutrients, metals distributions, and biological indices were typically more oceanic, while river and tidal effects were less evident in the data.

179. Release of dredged material at the experimental disposal area was not detectable in the water column nutrient and metal data. Dissolved and particulate samples collected at the experimental disposal area during and following disposal exhibited some random variation; this variation, however, was undoubtedly due to the analysis of seawater samples near analytical detection limits. There was some evidence in surface waters of metal input (especially nickel) to this

area from the Columbia River. Particulate concentrations of nickel near 3 μg/ℓ were found in surface waters during August 1975. Other nickel values, both dissolved and particulate, generally were less than 1 μg/ℓ, but even the higher concentrations do not represent a pollution source.

Sediment characteristics

180. Sediment samples analyzed from the vicinity of disposal area B consistently displayed elevated levels of nutrients and metals when compared with adjacent areas not previously affected by disposal operations. The abundance of more highly organic, very fine sand to silty samples (3.25 to 4.5 ϕ) in this area reasonably well explains these observed trends. The spatial distribution of these finer-grained sediments was documented by the grain-size and other mineralogic analyses performed by the physical contractor. The combined effects of previous disposal operations in this area have produced a noticeable bathymetric feature situated on the tidal delta.

River sediment

181. Disposal of approximately 459,000 m^3 of dredged material at the experimental disposal area had no discernible effect on the sediment chemistry at the area. Prior to disposal, sediment nutrient and metal concentrations in the area showed little variation (either spatial or with depth in the core) and were near or below background levels for each parameter. Following disposal, nearly identical background levels of each parameter were observed at the area, suggesting that the riverine sediments released at the area were chemically similar to the ambient shelf sediments. The disposal experiment, however, slightly altered the grain-size structure of the sediments at the area through the introduction of slightly coarser riverine sediments.

Benthic Studies

Benthic community structure

182. The distribution of benthic assemblages and species groups and the values of community structure parameters for the study area

were determined from samples of an areal baseline of 100 benthic stations sampled in December 1974 and January 1975. Through the use of Bray-Curtis numerical classification methods, similarity coefficients were calculated for each species, group, or station, and 5 major benthic assemblages and 12 station groups were found in the study area.

183. With the exception of assemblage C (southern inshore sand assemblage), species composition, biomass, and density values for these assemblages were different or greater than values reported for other benthic assemblages along the Oregon-Washington shelf. It is speculated that the Columbia River and its associated sedimentation patterns and high primary productivity produced these differences. Calculated species richness and diversity values were found to be related to sediment type and sediment stability. Diversity and species richness values generally increased offshore as a result of increased sediment stability due to reduced sediment agitation by winter storms. The lowest values of diversity and species richness were found at inshore stations that had considerable seasonal changes in sediment texture as a result of the combined effects of winter storms and the deposition of fine-grained sediments during periods of high Columbia River discharge. Macrofaunal biomass and density values were found to be related to the percent of organic material in the sediments. In general, macrofaunal densities and biomass increased offshore, as did the percent of organic matter in the sediments.

Effects of disposal on benthos

184. Analysis of macrofaunal density data from seven stations sampled within the experimental disposal area immediately prior to disposal showed that, for all species combined, there was no significant difference in density among these stations. In order to evaluate disposal effects on the benthos at the disposal area, postdisposal stations were separated in to three groups based on sediment texture: (a) affected stations exposed to direct burial, (b) intermediate stations located on the slope and edge of the deposit, and (c) unaffected stations outside the area of deposition. The stations exposed to direct burial by dredged material had signficantly higher diversity and evenness

values and significantly lower density of macrofauna than unaffected stations. These diversity differences persisted for a minimum of 8 months after disposal, and the density differences persisted for the duration of the sampling program (10 months after disposal).

185. Analysis of the effects of disposal on the 31 dominant species indicated that about half (15 of 31) of the species at the affected stations had lower densities after disposal; densities for the remaining dominant species of these stations apparently were not significantly affected by disposal. Similar trends were found for ranked seasonal abundances, (16 of 31 significant); however, there appeared to be no relationship between seasonal abundance differences between stations. Organism impacts were limited to those physical effects associated with disposal of large amounts of dredged material.

Recolonization of disposal area

186. Repopulation of the disposal area following disposal was probably accomplished by benthos digging up through the dredged material or migrating into the area or by reproduction and/or recruitment of benthos from outside the affected area. There is very little evidence showing that benthos were transported to the disposal area via dredged material.

Plankton Studies

187. The effects of disposal on zooplankton and ichthyoplankton communities could not be evaluated during these studies. Difficulties encountered in timing the release of dredged materials at the experimental area, problems associated with identification and quantification of the tow data, uncertainties regarding the diel activity patterns of many of the zooplankton species, and the overwhelming tidal and river discharge effects all combined to make any useful comparisons of catch data impossible. It is recommeded that subsequent studies of plankton communities be limited to laboratory evaluations using only polluted sediments.

Demersal Fish and Decapod Shellfish Studies

188. Fish trawling cruises during these studies yielded a total of 86,931 finfish from 51 species and a total of 97,360 decapod shellfish from 13 species. There was some indication from the trawl data that spatial differences occurred in some of the dominant finfish catches. Some of the dominant species were principally taken north of the Columbia River, while others occurred primarily south of the river. Whitebait smelt, English sole, and Pacific tomcod were found at all stations, while anchovy and longfin smelt were found at all stations in representative numbers except the experimental disposal area.

189. Finfish catch data were used to calculate various measures of community structure. Test indices showed a large amount of spatial and temporal variation; however, no significance test was performed to document this variation. There was some indication that catch data for the experimental disposal area showed depressed values of species diversity, species richness, and catch per unit effort following disposal. This condition apparently persisted for several months after disposal.

190. Analysis of variance methods were used to compare the numbers of fish and shellfish taken from the five sampling stations for the months of July, August, and September 1975 and April 1976. Significant spatial or site differences were found in 10 of the 11 numerically important finfish species. There were no significant differences in the English sole catch data between sampling stations. Significant temporal differences in catch data were found in 9 of the 11 species, with anchovy and showy snailfish being the exceptions.

191. Food utilization studies conducted as part of these studies indicated that four invertebrate and one fish species were the most extensively consumed prey items in the study area. These were the cumacean, *Diastylopsis dawsoni*, the mysid, *Neomysis kadiakensis*, the amphipod, *Atylus tridens*, the shrimp, *Crangon* sp., and the anchovy, *Engraulis mordax*.

192. Disposal effects and how they related to changes in the fish feeding patterns were difficult to assess due to uncertainties as to

where the fish fed before being captured. The data, however, do suggest that the consumption of small prey organisms such as cumaceans, copepods, mysids, and amphipods decreased immediately following disposal, while the relative percentages of larger organisms consumed increased after disposal.

193. In summary, the release of dredged material at the experimental disposal area had an apparent effect on the number of finfish species, number of individuals, size of the fish, and the particular food they consumed. The finfish population, however, appeared to have recovered within several months. The catch data during the study indicated that greater numbers of finfish occurred in the northern areas, especially during the summer months. The presence of greater numbers of demersal fish in this area should be considered during selection of future disposal areas.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Boone, Charles G
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1. Aquatic environment. 2. Bottom sediment. 3. Columbia River. 4. Dredged material. 5. Dredged material disposal. 6. Field investigations. 7. Sedimentation. 8. Waste disposal sites. I. Farrell, Michael P., joint author. II. Granat, Mitchell Alan, joint author. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-30.
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